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(54) **LASER-SCRIBING TOOL ARCHITECTURE**

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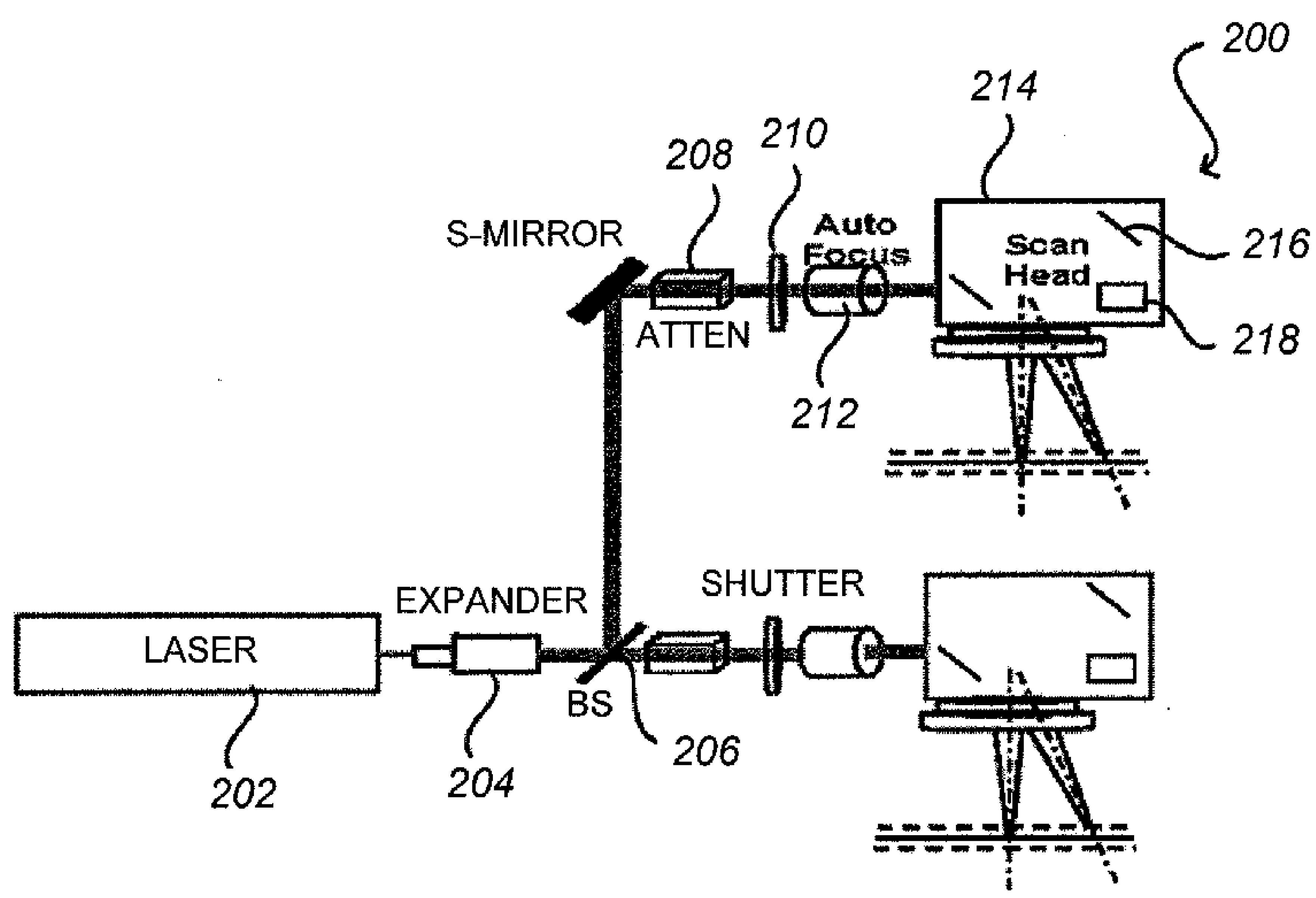
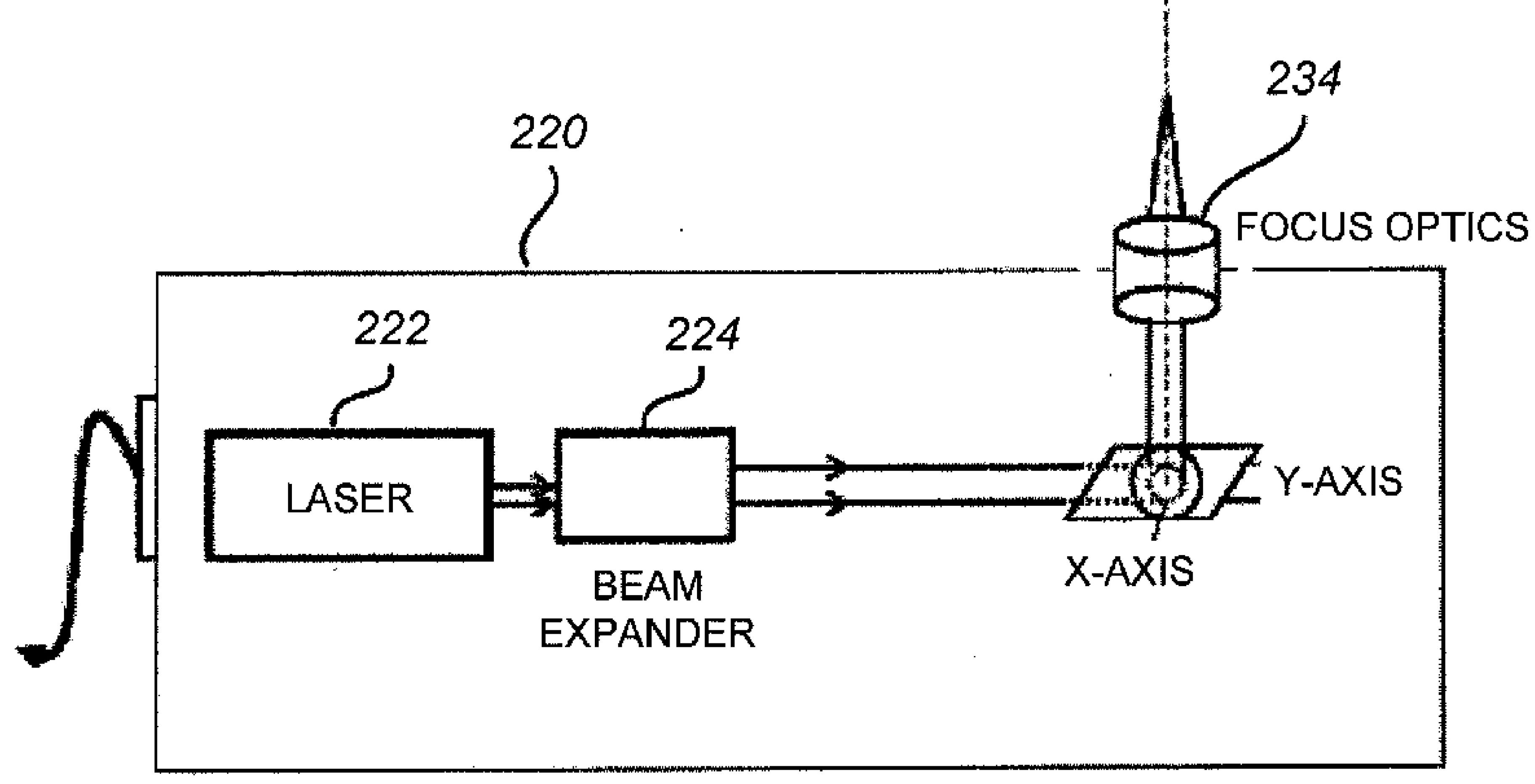
(57) **ABSTRACT**

The present disclosure relates to apparatuses and systems for laser scribing a vertically-oriented workpiece. In many embodiments, a laser-scribing apparatus includes a frame, a first fixture coupled with the frame, a second fixture coupled with the frame, a laser operable to generate output able to remove material from at least a portion of the workpiece, and a scanning device coupled with the laser and the frame. The first fixture is configured for engagement with a first portion of the workpiece. The second fixture is configured for engagement with a second portion of the workpiece. When the workpiece is engaged by the first and second fixtures the workpiece is substantially vertically oriented. The scanning device is operable to control a position of the output from the laser relative to the workpiece.





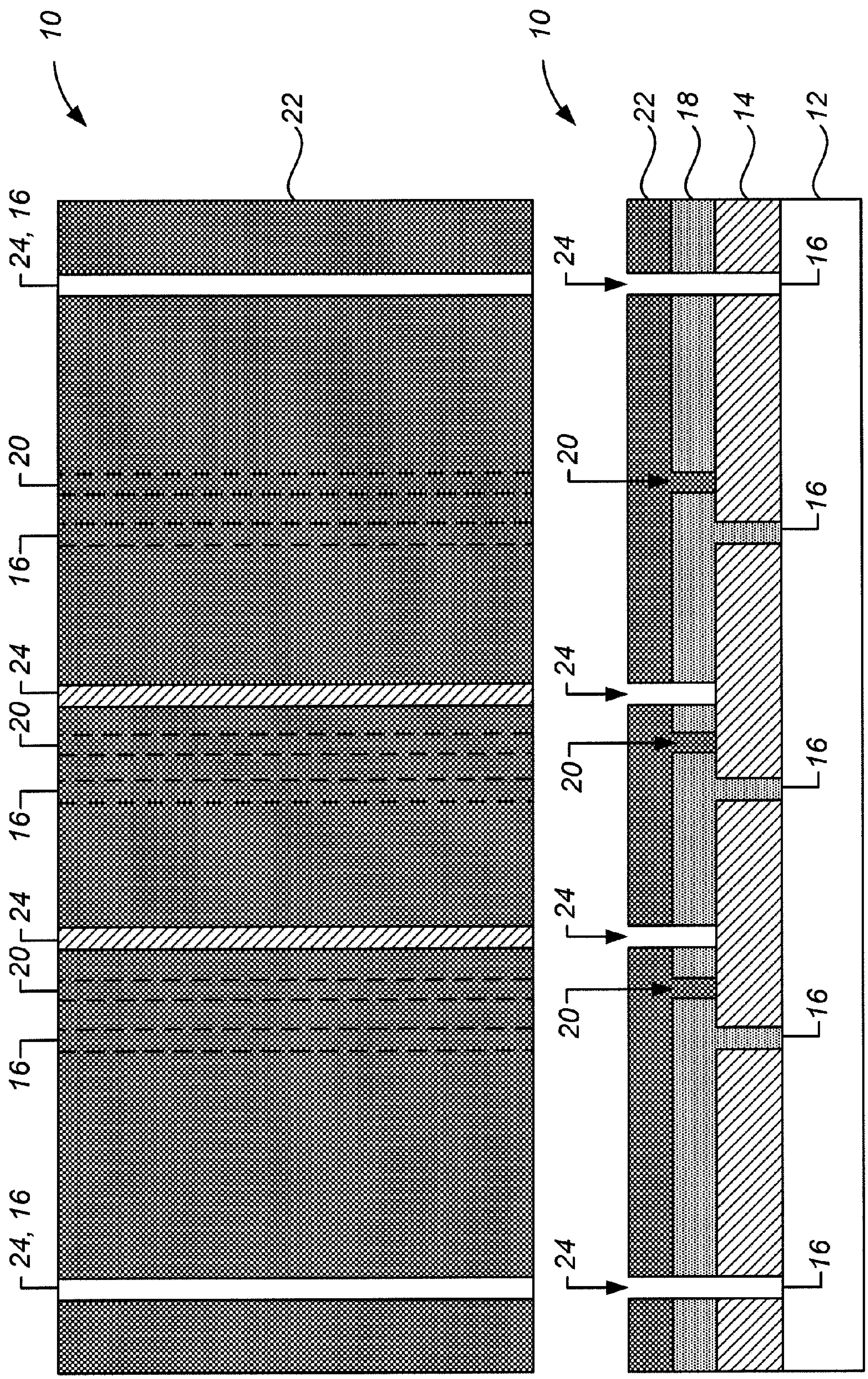

10
22
24, 16
20
16
24
20
16
24
20
16
24, 16
10
22
18
14
12
24
16
20
16
24
20
16
24
20
16
24
16

FIG. 1

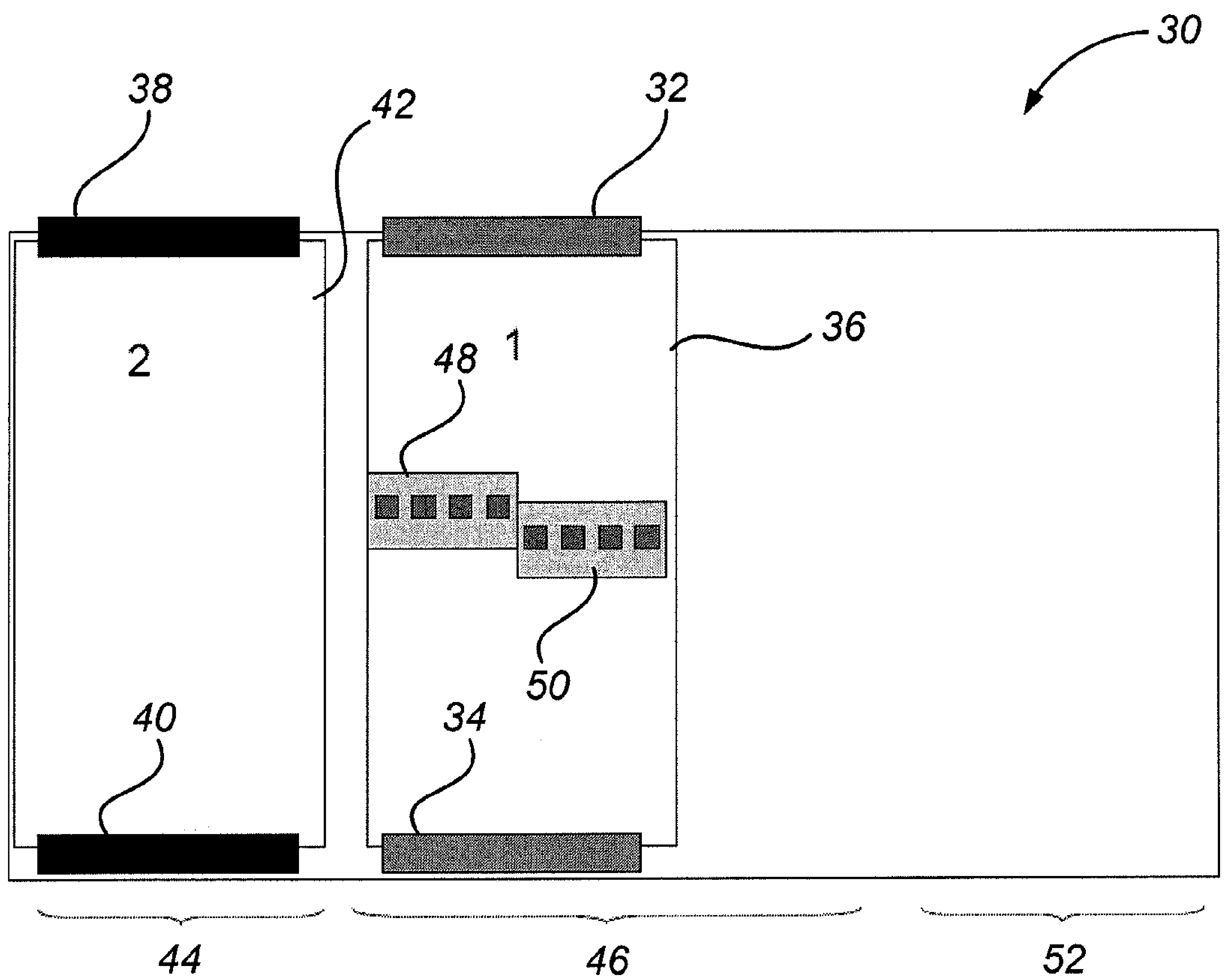


FIG. 2A

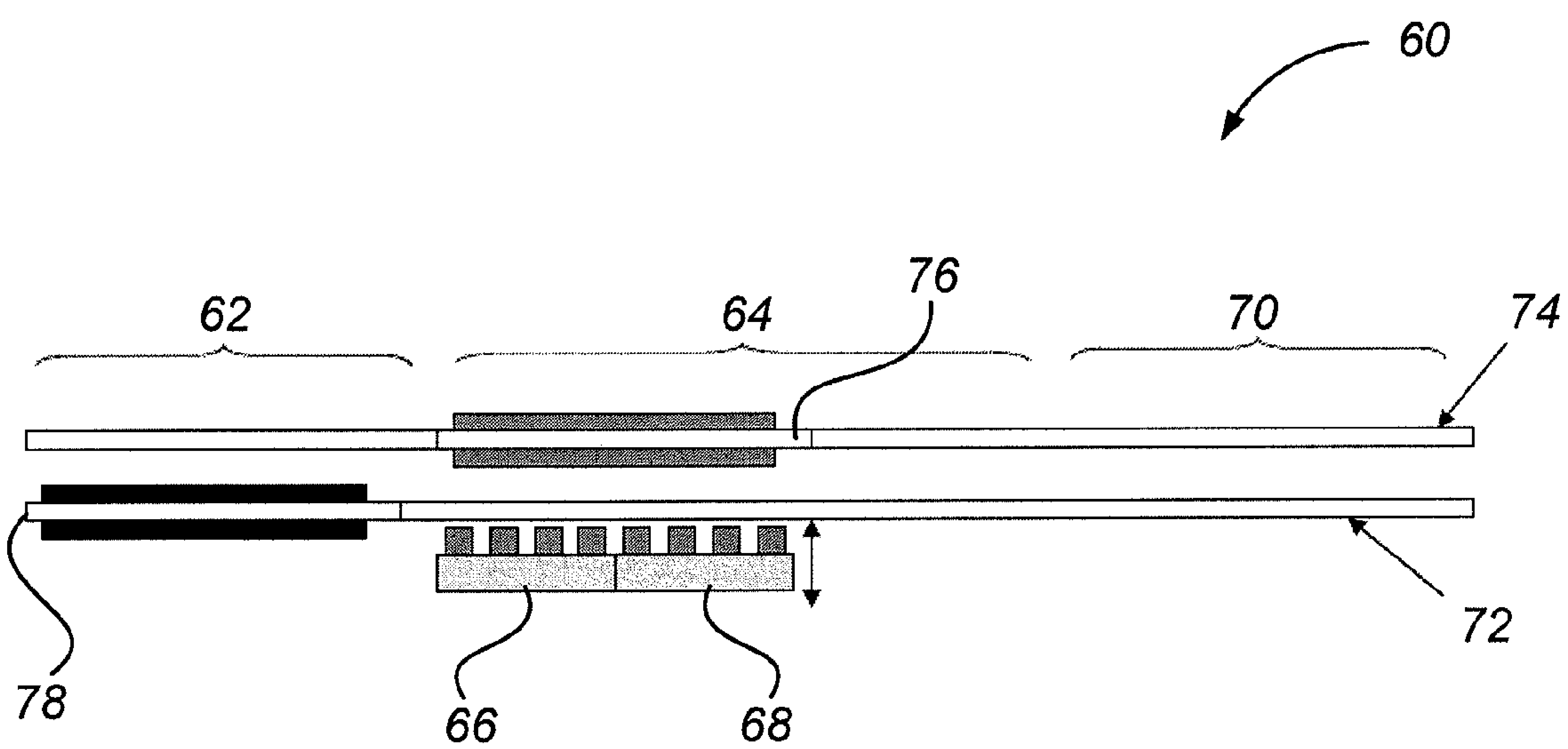


FIG. 2B

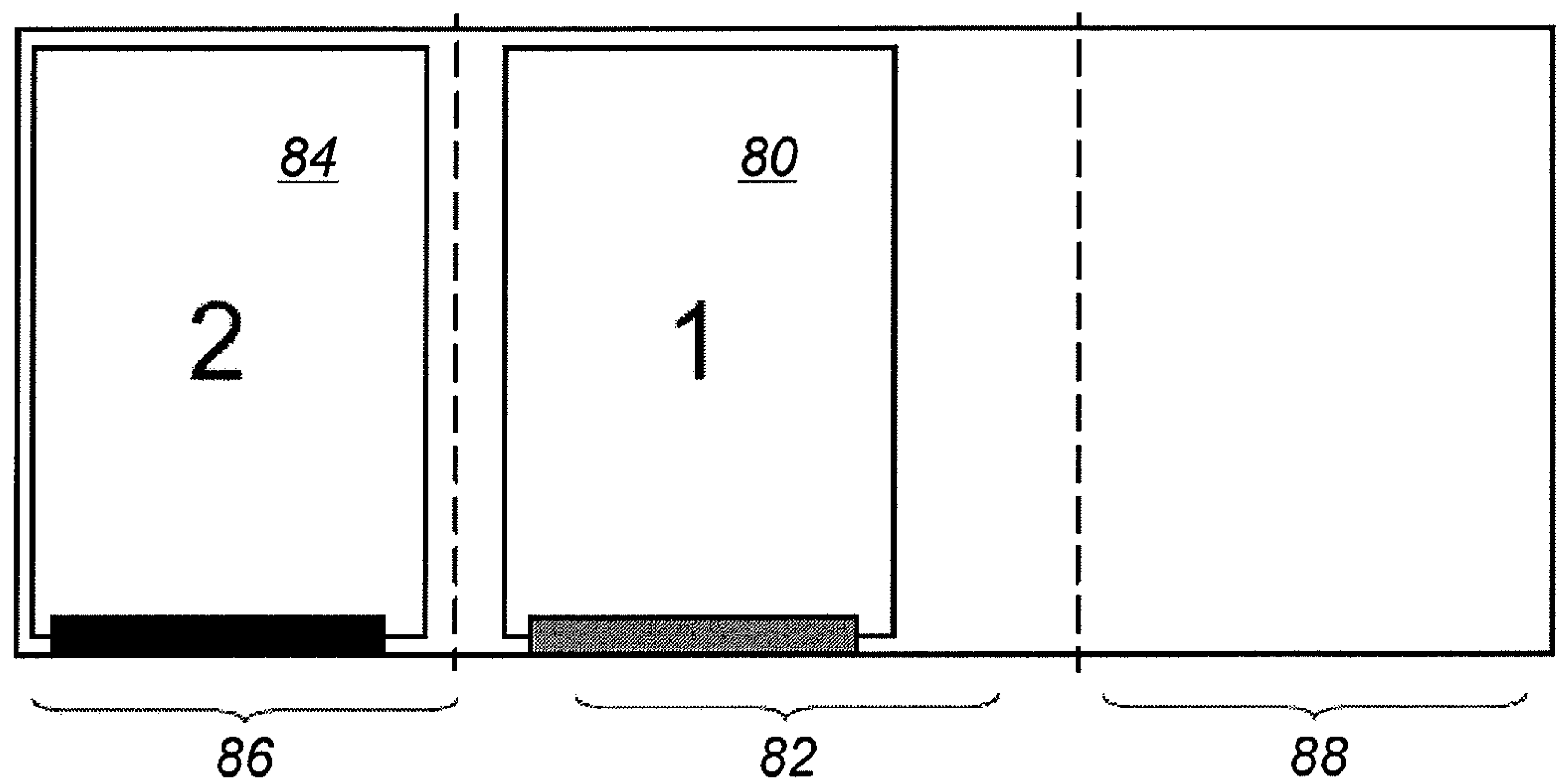


FIG. 3A

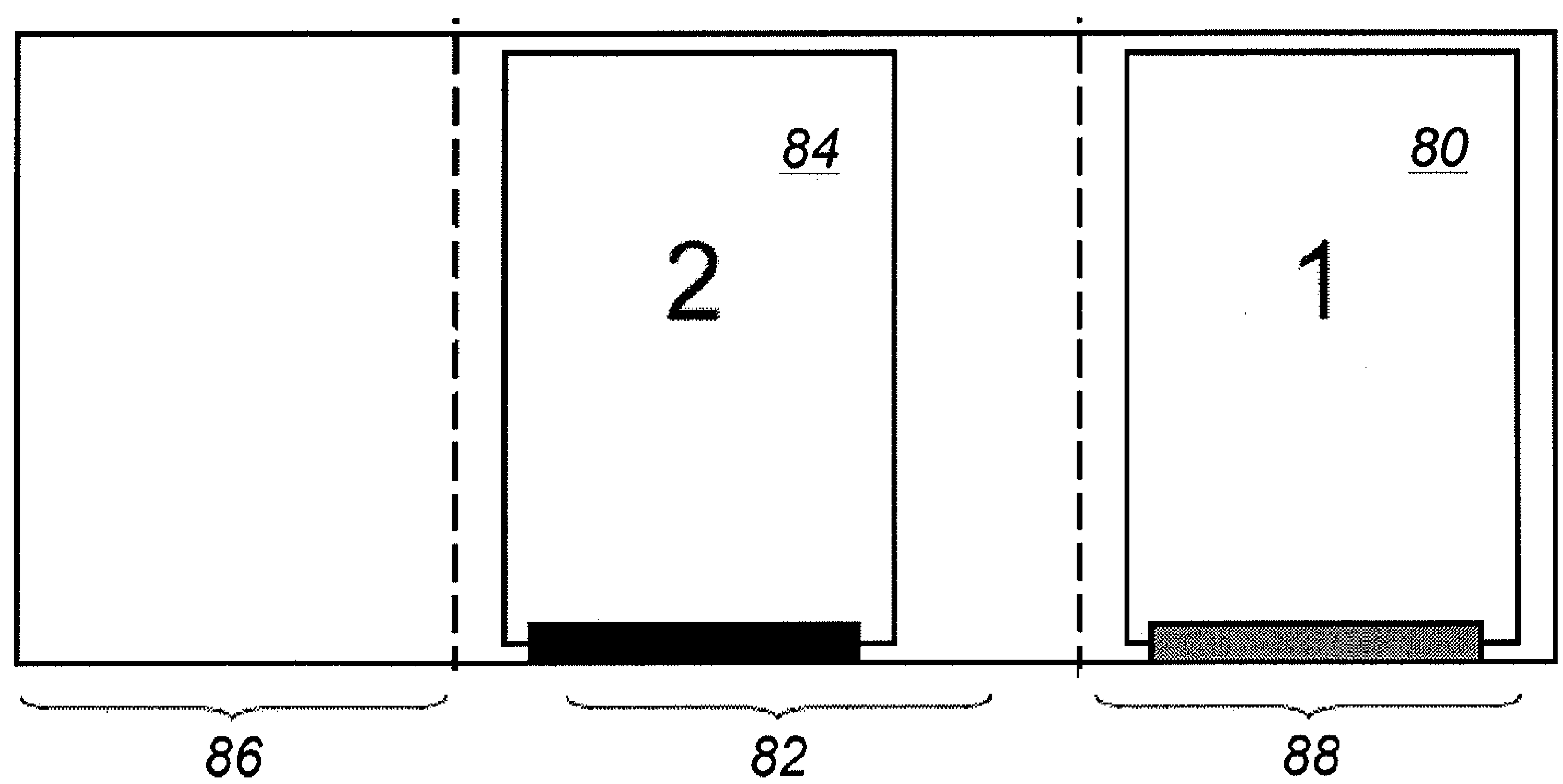


FIG. 3B

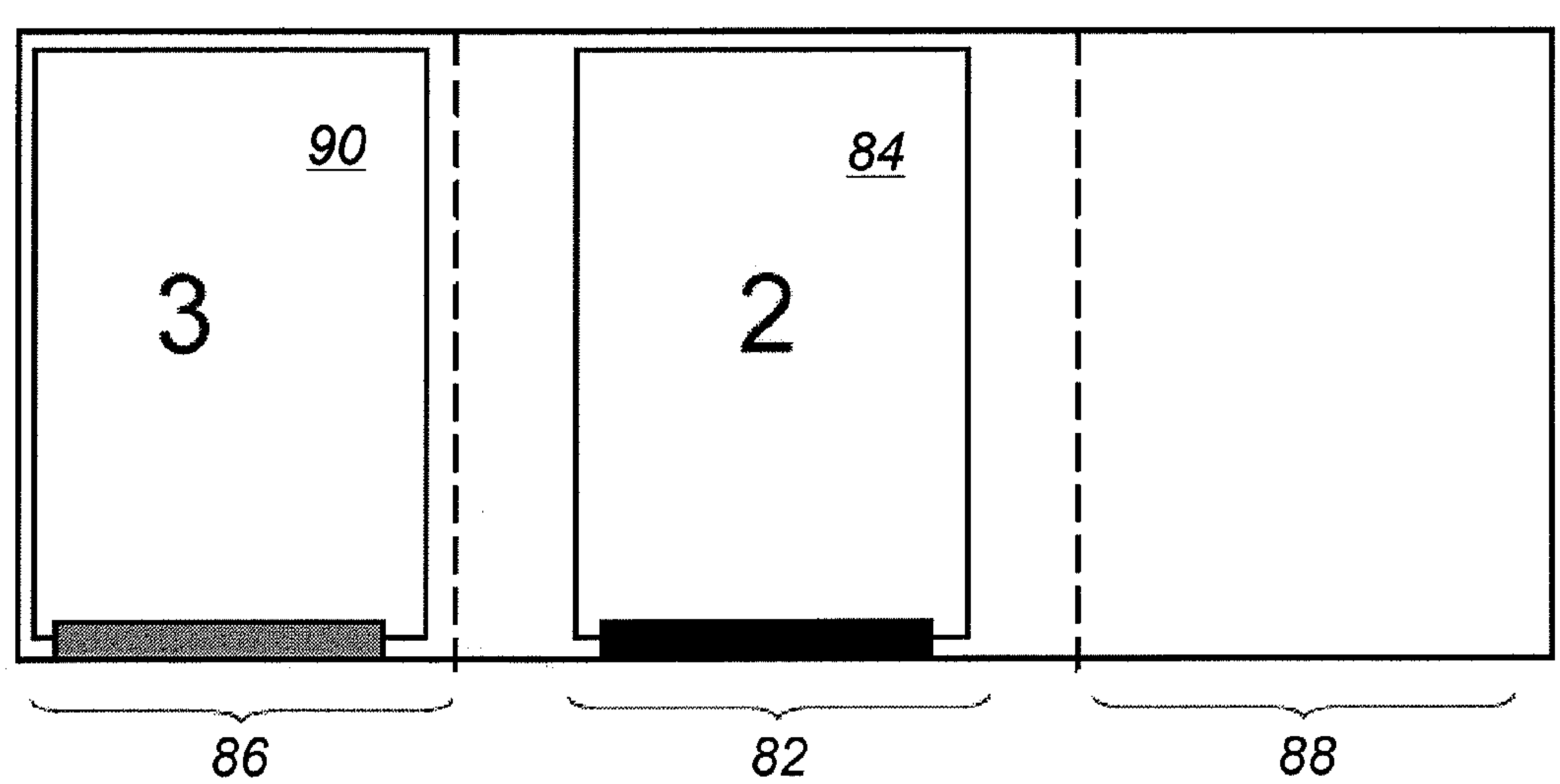


FIG. 3C

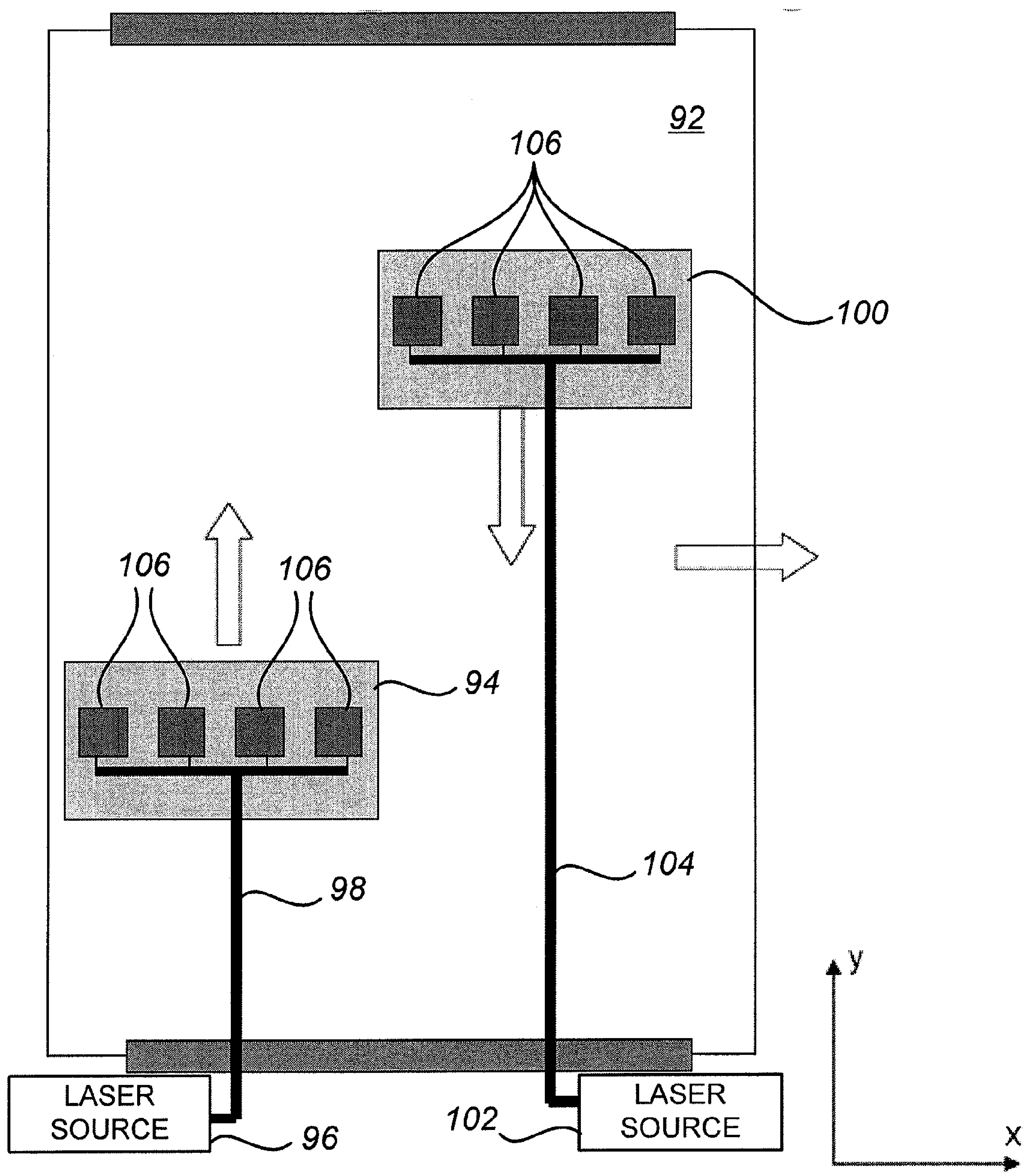

92
106
100
106
106
94
98
104
LASER SOURCE
96
102
LASER SOURCE
y
x

FIG. 4

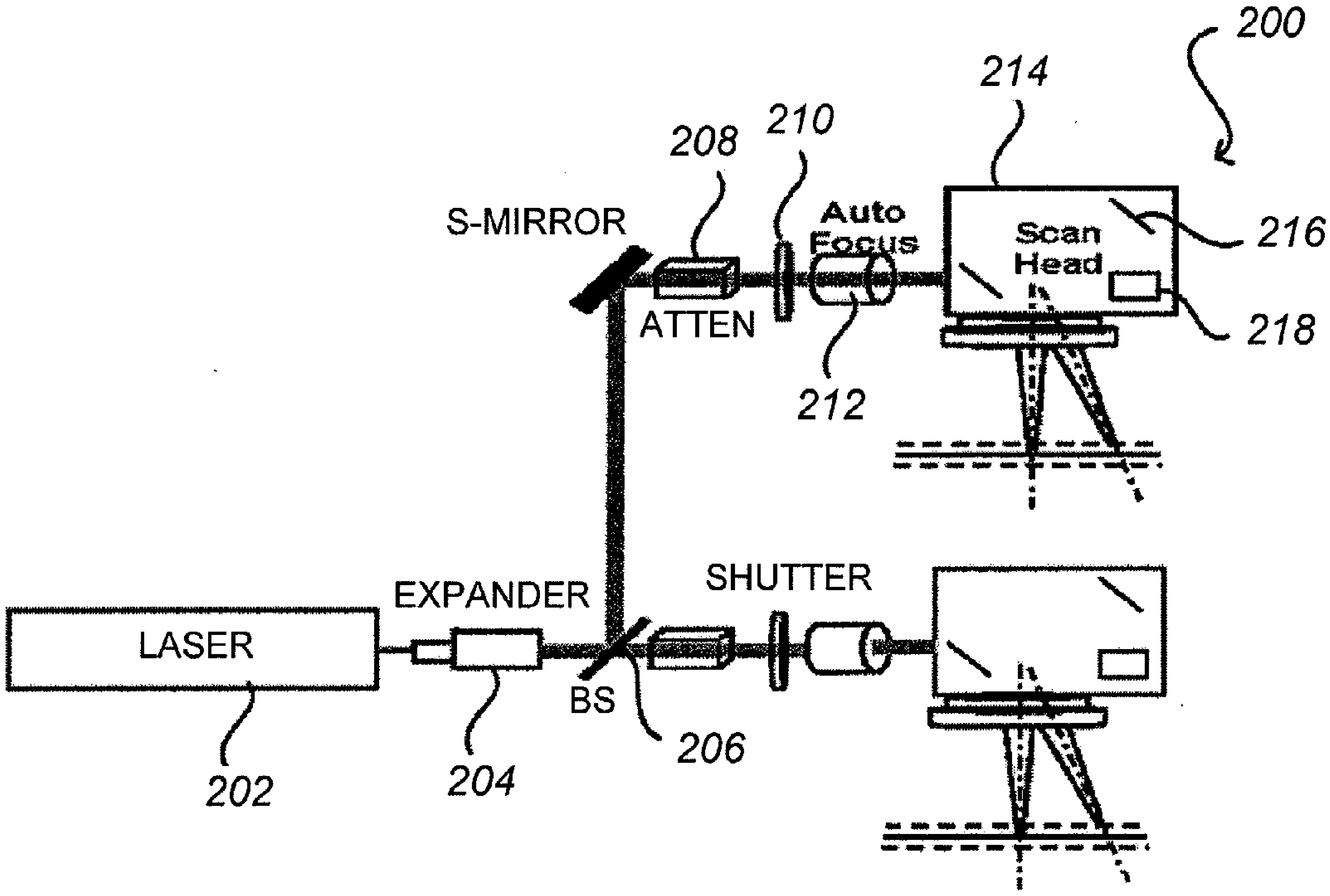

200
214
210
208
Auto Focus
Scan Head
216
S-MIRROR
218
ATTEN
212
SHUTTER
EXPANDER
LASER
BS
206
202
204

FIG. 5A

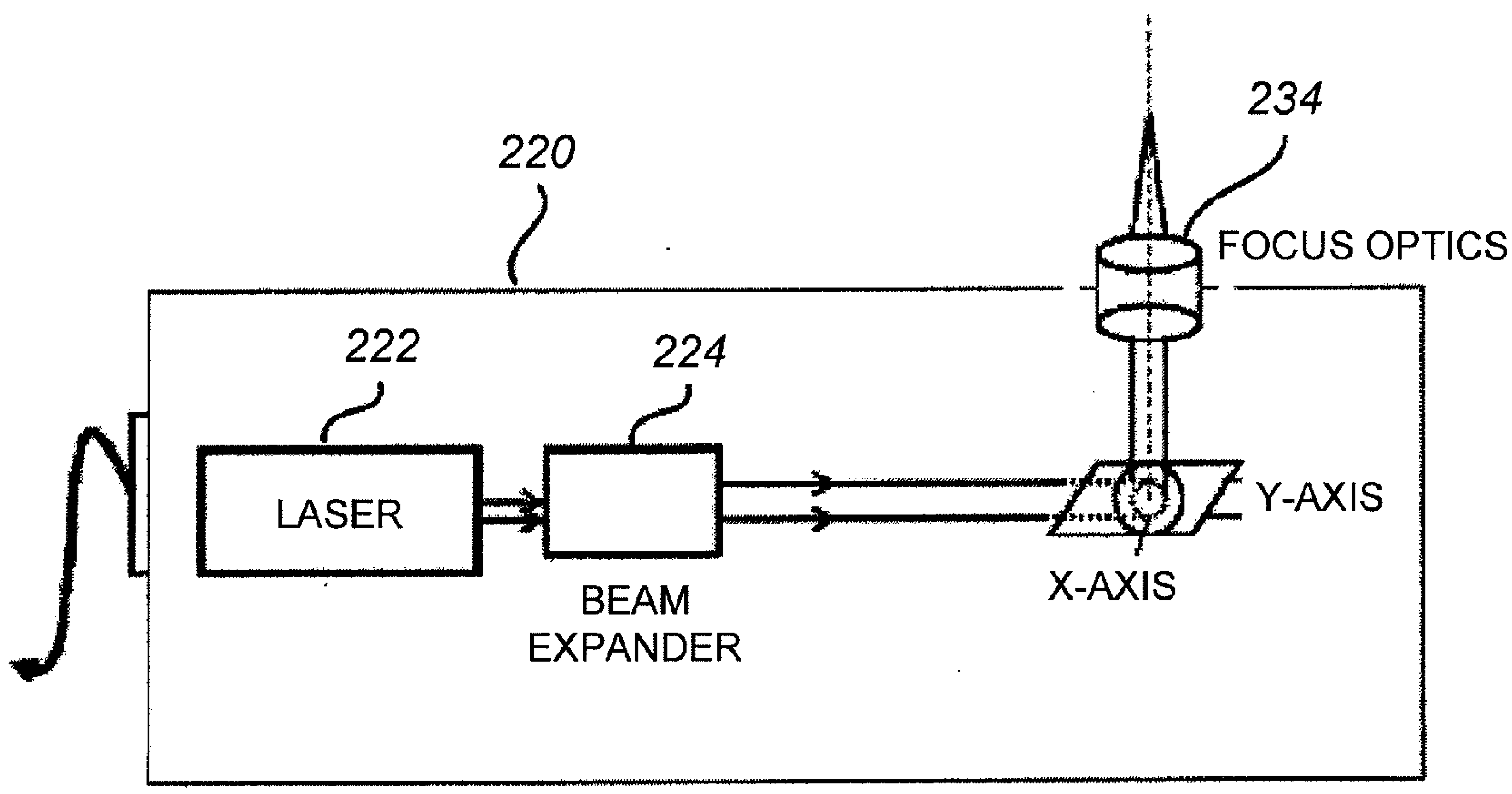

234
220
FOCUS OPTICS
222
224
LASER
Y-AXIS
X-AXIS
BEAM
EXPANDER

FIG. 5B

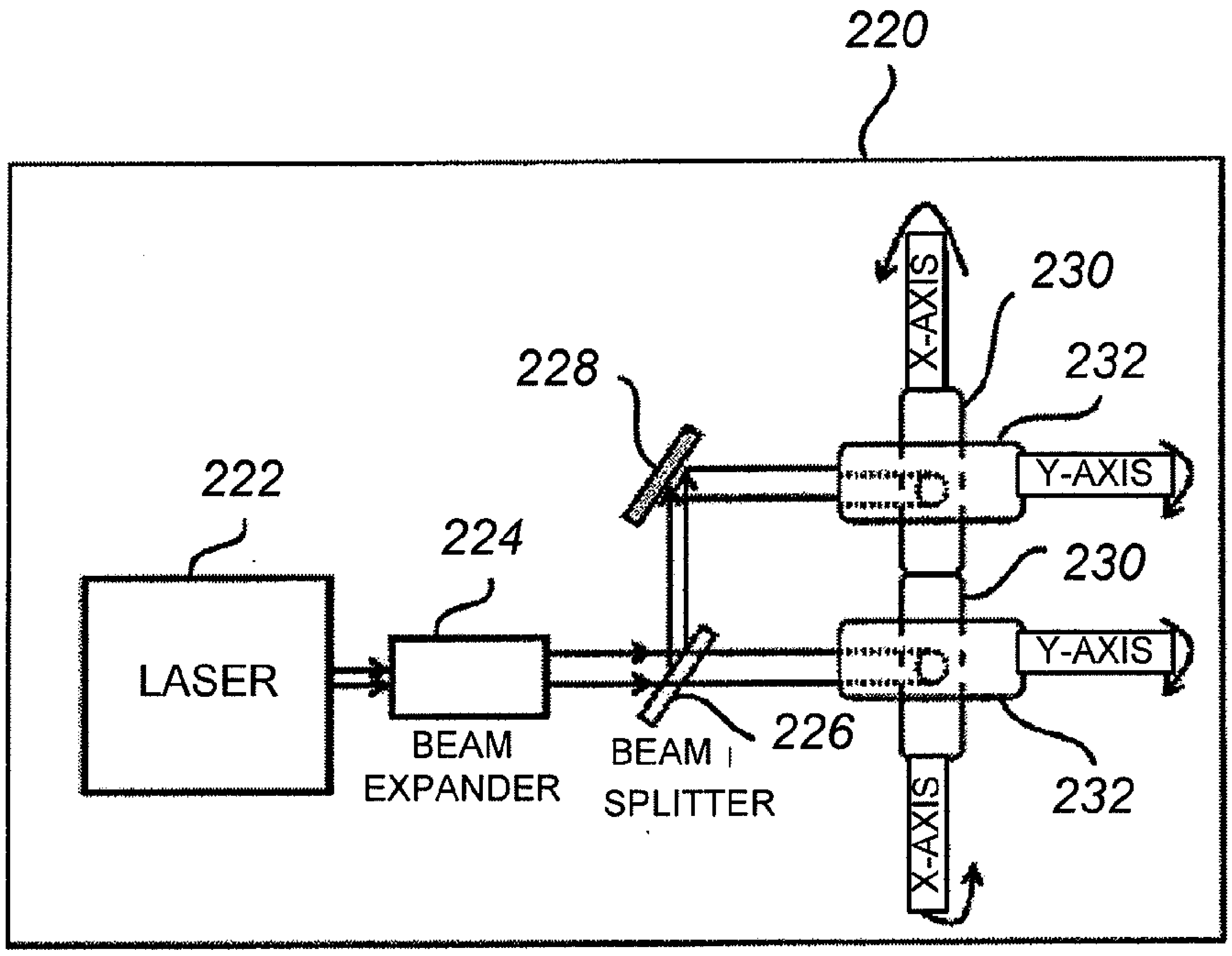

220
230
232
228
222
224
230
LASER
X-AXIS
Y-AXIS
Y-AXIS
BEAM
EXPANDER
BEAM
SPLITTER
226
232
X-AXIS

FIG. 5C

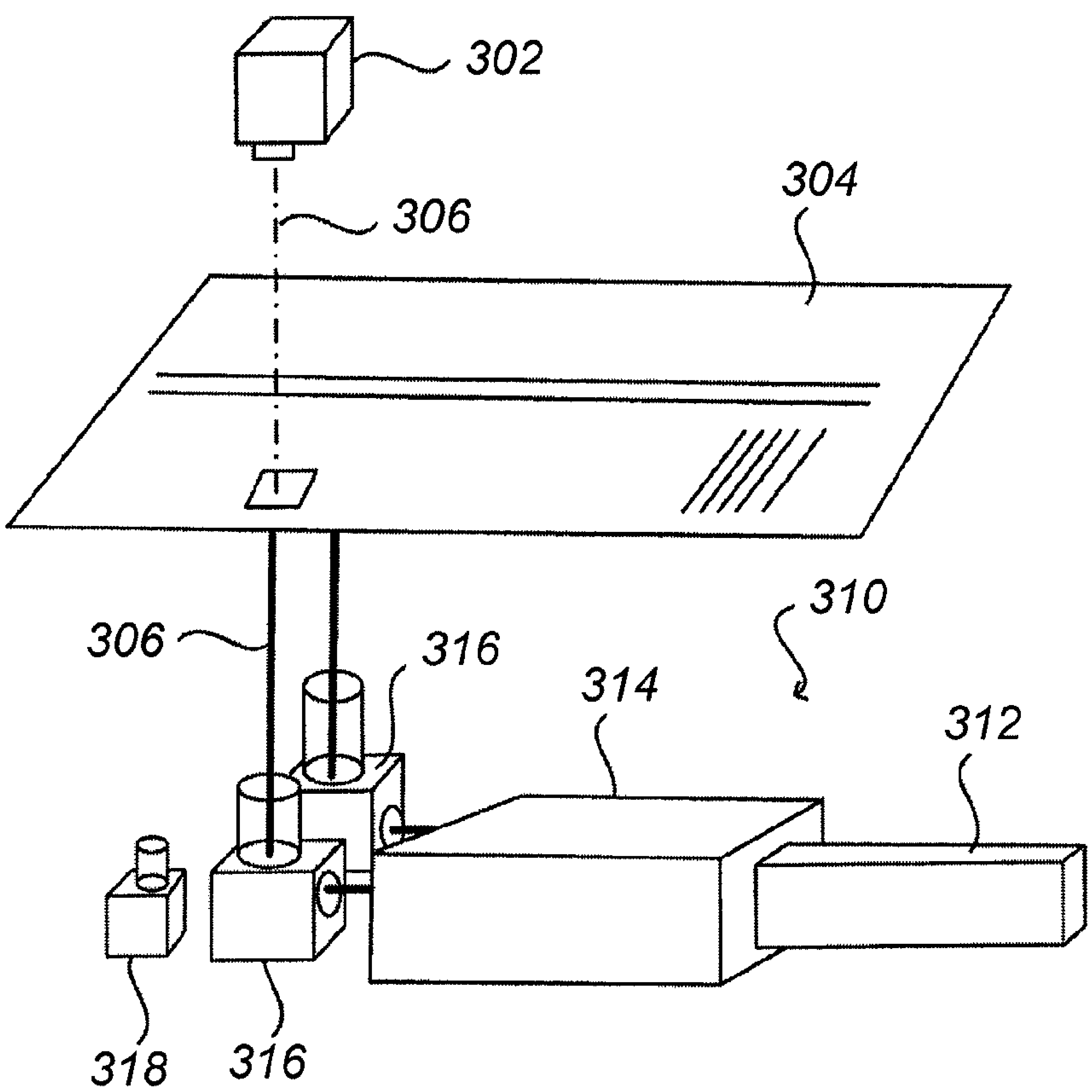

302
306
304
310
306
316
314
312
318
316

FIG. 6

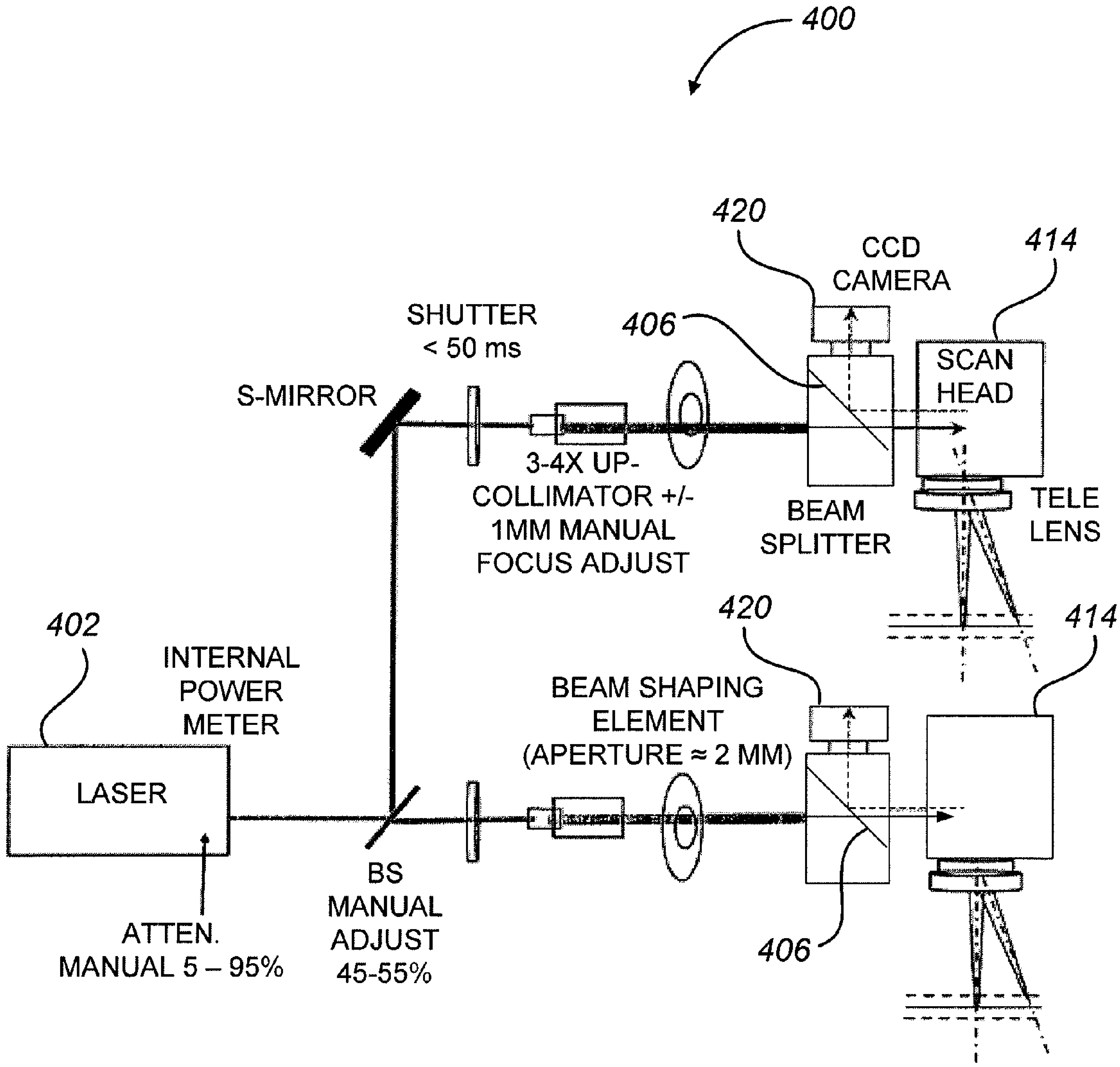

400
420
CCD CAMERA
414
SHUTTER < 50 ms
406
SCAN HEAD
S-MIRROR
3-4X UP-COLLIMATOR +/- 1MM MANUAL FOCUS ADJUST
BEAM SPLITTER
TELE LENS
402
INTERNAL POWER METER
420
414
BEAM SHAPING ELEMENT (APERTURE ≈ 2 MM)
LASER
BS MANUAL ADJUST 45-55%
ATTEN. MANUAL 5 – 95%
406

FIG. 7

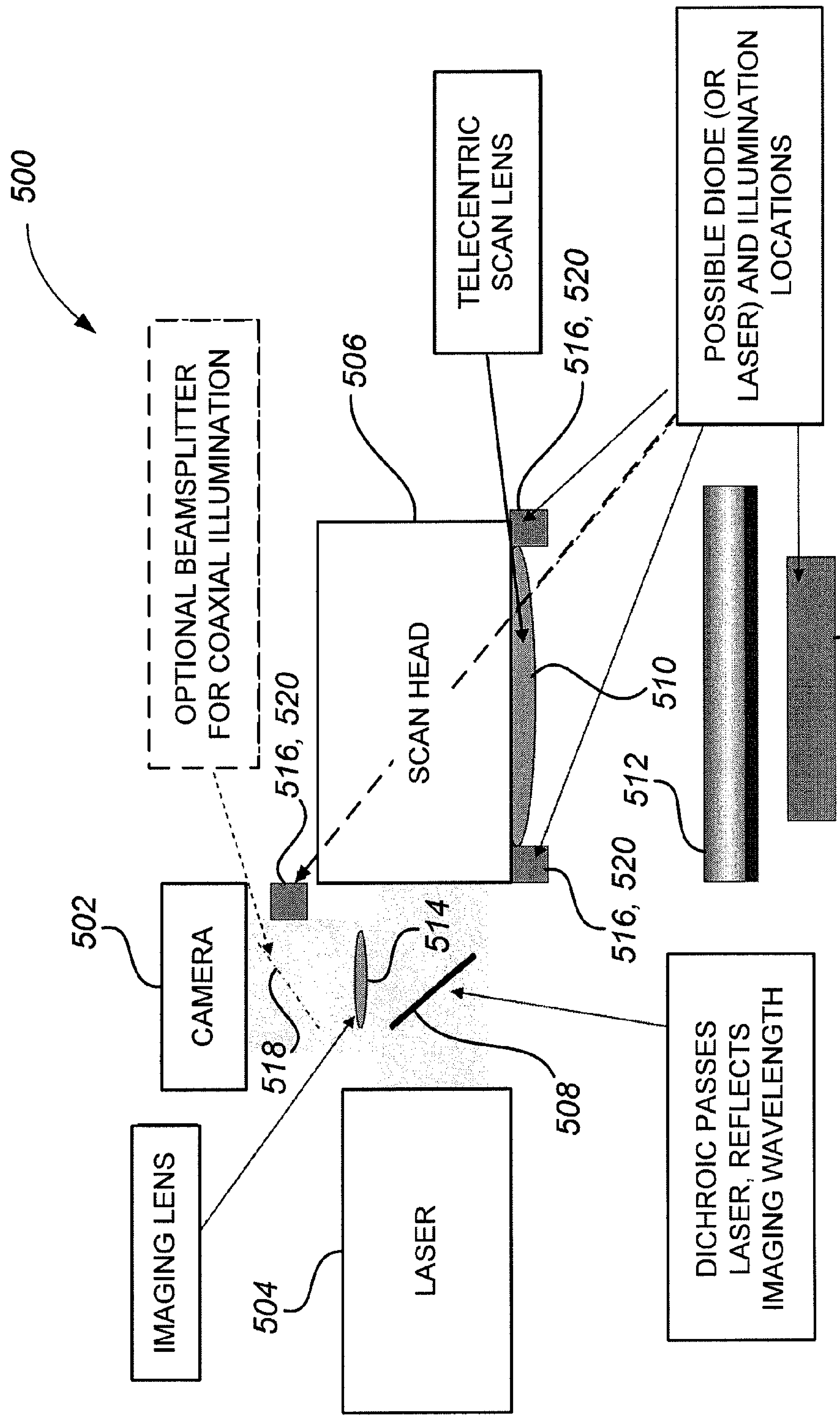

500
OPTIONAL BEAMSPLITTER FOR COAXIAL ILLUMINATION
506
SCAN HEAD
TELECENTRIC SCAN LENS
516, 520
POSSIBLE DIODE (OR LASER) AND ILLUMINATION LOCATIONS
516, 520
516, 520
510
512
516, 520
502
CAMERA
514
518
IMAGING LENS
508
LASER
504
DICHROIC PASSES LASER, REFLECTS IMAGING WAVELENGTH

FIG. 8

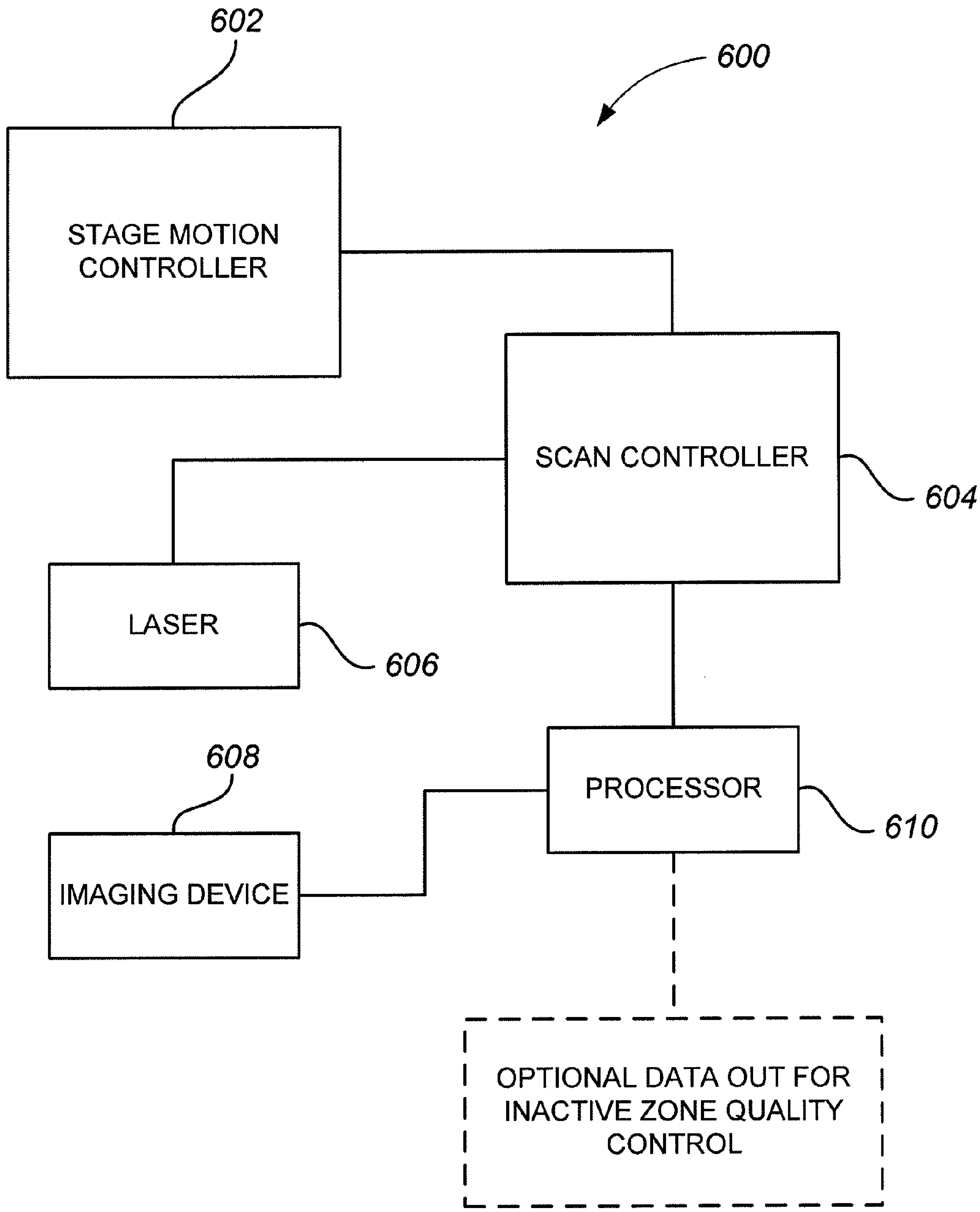

602
600
STAGE MOTION CONTROLLER
SCAN CONTROLLER
604
LASER
606
608
PROCESSOR
610
IMAGING DEVICE
OPTIONAL DATA OUT FOR INACTIVE ZONE QUALITY CONTROL

FIG. 9

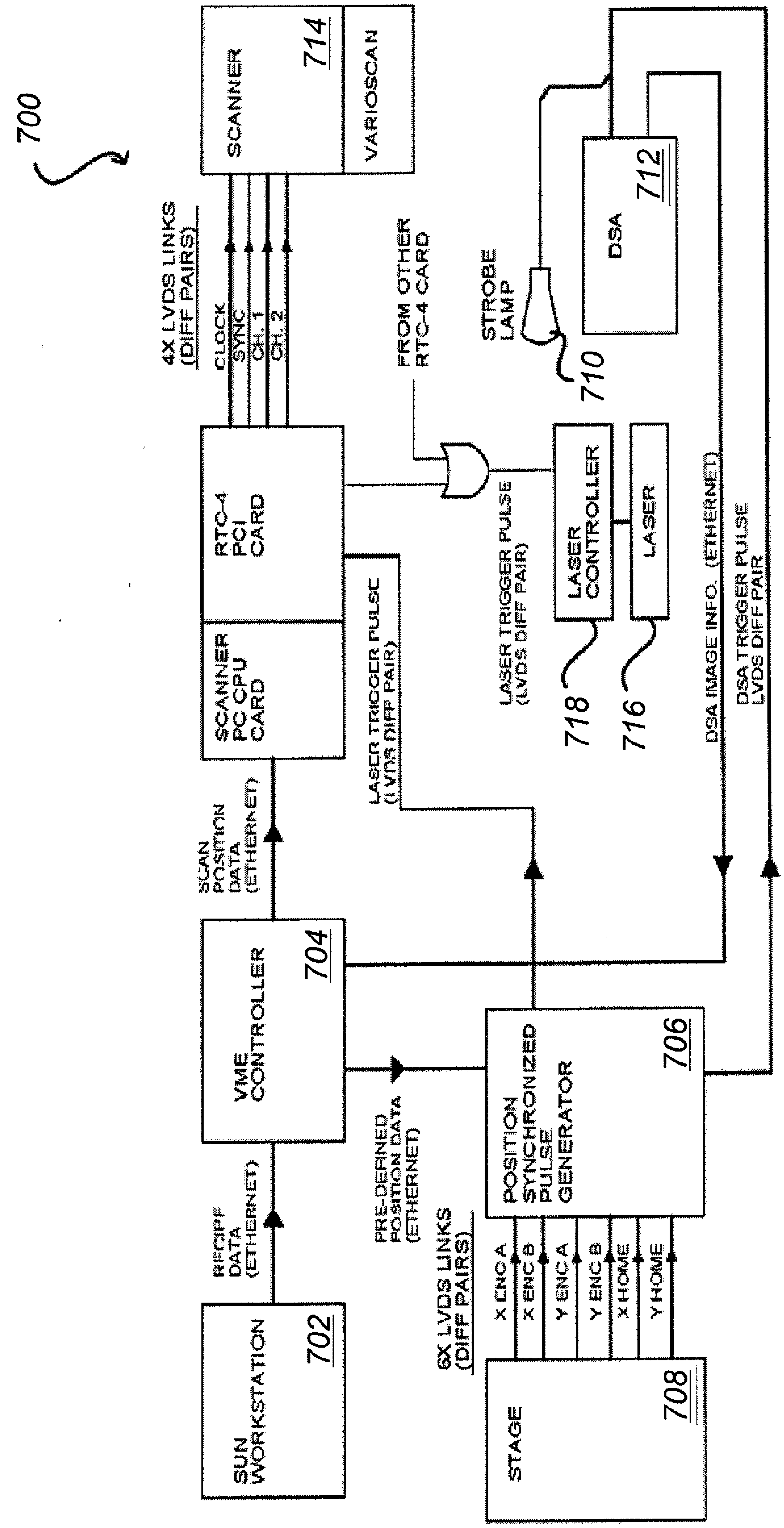

700
SUN WORKSTATION
702
RECIPE DATA (ETHERNET)
VME CONTROLLER
704
SCAN POSITION DATA (ETHERNET)
SCANNER PC CPU CARD
RTC-4 PCI CARD
4X LVDS LINKS (DIFF PAIRS)
CLOCK
SYNC
CH. 1
CH. 2
SCANNER
714
VARIOSCAN
PRE-DEFINED POSITION DATA (ETHERNET)
POSITION SYNCHRONIZED PULSE GENERATOR
706
6X LVDS LINKS (DIFF PAIRS)
X ENC A
X ENC B
Y ENC A
Y ENC B
X HOME
Y HOME
STAGE
708
LASER TRIGGER PULSE (LVDS DIFF PAIR)
FROM OTHER RTC-4 CARD
LASER TRIGGER PULSE (LVDS DIFF PAIR)
LASER CONTROLLER
LASER
718
716
STROBE LAMP
710
DSA
712
DSA IMAGE INFO. (ETHERNET)
DSA TRIGGER PULSE LVDS DIFF PAIR

FIG. 10

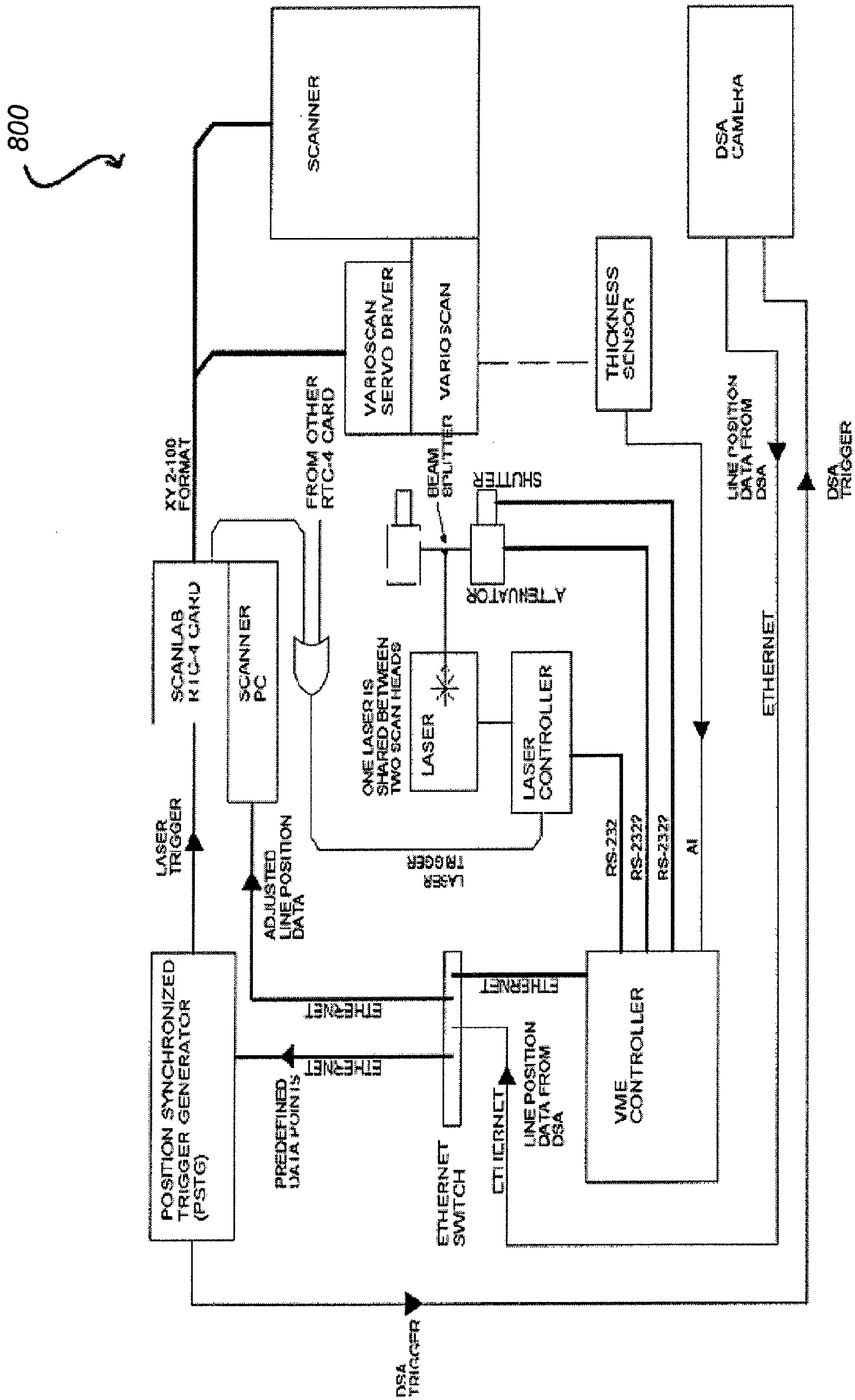

800
SCANNER
DSA CAMERA
VARIOSCAN SERVO DRIVER
VARIOSCAN
THICKNESS SENSOR
XY 2-100 FORMAT
FROM OTHER RTC-4 CARD
BEAM SPLITTER
SHUTTER
ATTENUATOR
LINE POSITION DATA FROM DSA
DSA TRIGGER
SCANLAB RTC-4 CARD
SCANNER PC
ONE LASER IS SHARED BETWEEN TWO SCAN HEADS
LASER
LASER CONTROLLER
ETHERNET
LASER TRIGGER
ADJUSTED LINE POSITION DATA
RS-232
RS-232?
AI
POSITION SYNCHRONIZED TRIGGER GENERATOR (PSTG)
PREDEFINED DATA POINTS
ETHERNET SWITCH
VME CONTROLLER

FIG. 11

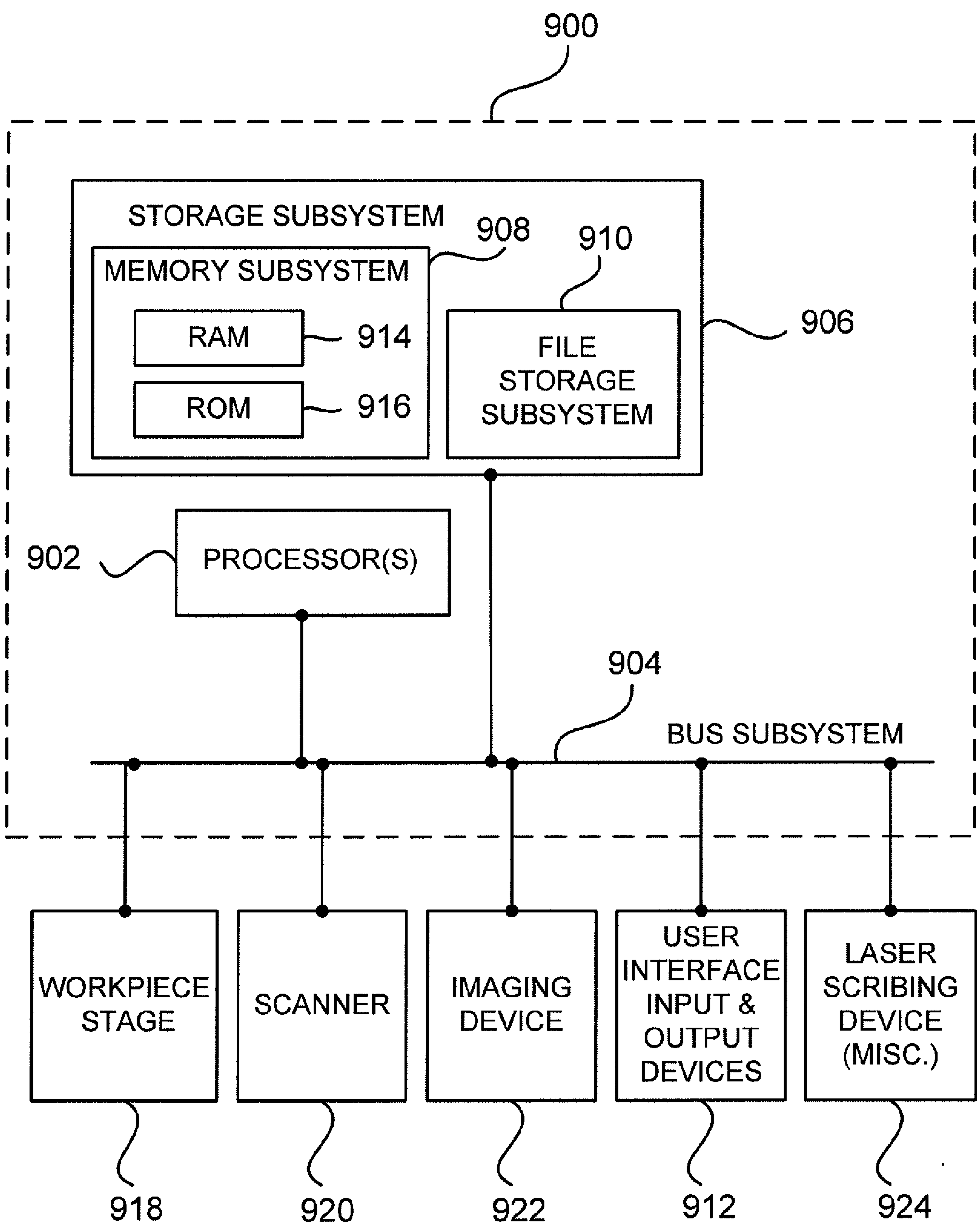

900
STORAGE SUBSYSTEM
908
910
MEMORY SUBSYSTEM
RAM
914
ROM
916
FILE STORAGE SUBSYSTEM
906
902
PROCESSOR(S)
904
BUS SUBSYSTEM
WORKPIECE STAGE
SCANNER
IMAGING DEVICE
USER INTERFACE INPUT & OUTPUT DEVICES
LASER SCRIBING DEVICE (MISC.)
918
920
922
912
924

FIG. 12

LASER-SCRIBING TOOL ARCHITECTURE

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/116,257, filed on Nov. 19, 2008, entitled "Laser Scribing Tool Architecture," the entire disclosure of which is hereby incorporated herein by reference.

BACKGROUND

[0002] Various embodiments described herein relate generally to apparatuses and systems for scribing or patterning a workpiece, and more particularly to apparatuses and systems for laser scribing a workpiece placed in a vertical orientation. Such apparatuses and systems can be particularly effective for laser scribing glass substrates having at least one layer used to form thin-film solar cells.

[0003] Current methods for forming thin-film solar cells involve depositing or otherwise forming a plurality of layers on a substrate, such as a glass, metal or polymer substrate suitable to form one or more p-n junctions. An example thin-film solar cell includes a glass substrate having a transparent-conductive-oxide (TCO) layer, a plurality of doped and undoped silicon layers, and a metal back layer. Examples of materials that can be used to form solar cells, along with methods and apparatus for forming the cells, are described, for example, in co-pending U.S. patent application Ser. No. 11/671,988, filed Feb. 6, 2007, entitled "MULTI-JUNCTION SOLAR CELLS AND METHODS AND APPARATUSES FOR FORMING THE SAME," the entire disclosure of which is hereby incorporated herein by reference.

[0004] When a panel is formed from a large substrate, a series of laser-scribed lines is typically used within each layer to delineate individual cells. FIG. **1** diagrammatically illustrates an example solar-cell assembly **10** that includes scribed lines, for example, laser-scribed lines. The solar-cell assembly **10** can be fabricated by depositing a number of layers on a glass substrate **12** and scribing a number of lines within the layers. The fabrication process begins with the deposition of a TCO layer **14** on the glass substrate **12**. A first set of lines **16** ("P**1**" interconnect lines and "P**1**" isolation lines) are then scribed within the TCO layer **14**. A plurality of doped and undoped amorphous silicon (a-Si) layers **18** are then deposited on the TCO layer **14** and within the first set of lines **16**. A second set of lines **20** ("P**2**" interconnect lines) are then scribed within the silicon layers **18**. A metal layer **22** is then deposited on the silicon layers **18** and within the second set of lines **20**. A third set of lines **24** ("P**3**" interconnect lines and "P**3**" isolation lines) are then scribed as illustrated.

[0005] The cost of production and quality of thin-film solar cells are influenced by the cost of production and quality of the scribed assemblies (e.g., solar-cell assembly **10**) used to produce the solar cells. Accordingly, it is desirable to develop apparatuses and systems for scribing workpieces that have reduced cost and improved scribing quality. More particularly, it is desirable to develop improved apparatuses and systems for laser-scribing assemblies used to form thin-film solar cells.

BRIEF SUMMARY

[0006] The following presents a simplified summary of some embodiments of the invention in order to provide a basic understanding of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some aspects and embodiments in a simplified form as a prelude to the more detailed description that is presented later.

[0007] Apparatuses and systems in accordance with various aspects and embodiments are provided for laser scribing a workpiece. The disclosed apparatuses and systems are configured to laser scribe a vertically-oriented workpiece. Vertically orienting the workpiece may result in improved workpiece stability, improved ablation debris removal, improved throughput, reduced vibration levels, improved accuracy, smaller footprint, improved serviceability, and/or other such improvements. Such apparatuses and systems may be particularly effective when used to laser scribe assemblies used to form thin-film solar cells.

[0008] In a first aspect, an apparatus for laser scribing a workpiece comprising a substantially flat surface is provided. The apparatus includes a frame, a first fixture coupled with the frame, a second fixture coupled with the frame, a laser operable to generate output able to remove material from at least a portion of the workpiece, and a scanning device coupled with the laser and the frame. The first fixture is configured for engagement with a first portion of the workpiece. The second fixture is configured for engagement with a second portion of the workpiece. When the workpiece is engaged by the first and second fixtures the flat surface is substantially vertically oriented. The scanning device is operable to control a position of the output from the laser relative to the workpiece.

[0009] In many embodiments, the first and second fixtures are configured to engage different portions of a rectangular workpiece. For example, the first fixture can be configured to engage the workpiece along a first side and the second fixture can be configured to engage the workpiece along a second side opposite the first side. When the workpiece is engaged by the first and second fixtures, the first side can be disposed at the top of the workpiece and the second side can be disposed at the bottom of the workpiece. Additionally, when the workpiece is engaged by the first and second fixtures, the first and second sides can be substantially vertically oriented.

[0010] In many embodiments, the fixtures can be translatable relative to the frame and the apparatus can comprise additional fixtures. For example, the first and second fixtures can be horizontally translatable relative to the frame. The apparatus can comprise third and fourth fixtures coupled with the frame. The third fixture can be configured to engage a second workpiece along a first side of the second workpiece. The fourth fixture can be configured to engage the second workpiece along a second side of the second workpiece. When the second workpiece is engaged by the third and fourth fixtures a flat surface of the second workpiece is substantially vertically oriented. The third and fourth fixtures can be horizontally translatable relative to the frame.

[0011] In many embodiments, the apparatus can be configured to hold multiple workpieces. For example, in many embodiments, a workpiece can be loaded or unloaded while another workpiece is being scribed. A path of travel in the apparatus for a workpiece can be offset from a path of travel in the apparatus for a second workpiece.

[0012] In many embodiments, the scanning device is translatable relative to the workpiece and/or the frame. For example, the scanning device can be horizontally translatable so as to adjust for an offset between the paths of travel for the workpiece and the second workpiece. Such offset adjustment can also be achieved by changing the focus of the beam by optical means, such as with a three-dimensional scanner, and/or an adjustable beam expander. The scanning device can be vertically translatable relative to the workpiece and/or the frame.

[0013] In many embodiments, the apparatus comprises multiple scanning devices. For example, the apparatus can comprise a second scanning device coupled with the laser and the frame. The second scanning device is operable to control a position of the output from the laser relative to the workpiece. Both the scanning device and the second scanning device can be vertically translatable relative to the workpiece.

[0014] In many embodiments, the apparatus comprises one or more optical cables. For example, the apparatus can comprise an optical cable coupling the laser with the scanning device and can comprise a second optical cable coupling the laser with the second scanning device.

[0015] In many embodiments, the workpiece comprises a substrate and at least one layer used for forming a solar cell. In many embodiments, the laser is able to remove material from the at least one layer.

[0016] In another aspect, a system for laser scribing a workpiece comprising a substantially flat surface is provided. The system includes a frame, a first fixture coupled with the frame, a second fixture coupled with the frame, a laser operable to generate output able to remove material from at least a portion of the workpiece, a scanning device coupled with the laser and the frame, and a control device coupled with the laser and the scanning device. The first fixture is configured for engagement with a first portion of the workpiece. The second fixture is configured for engagement with a second portion of the workpiece. When the workpiece is engaged by the first and second fixtures, the flat surface is substantially vertically oriented. The scanning device is operable to control a position of the output from the laser relative to the workpiece. The control device includes a processor and a machine-readable medium. The machine-readable medium includes instructions that when executed by the processor cause the system to align the laser output in order to form a predetermined feature pattern on the workpiece.

[0017] In many embodiments, the scanning device and the workpiece are translatable. For example, the scanning device can be vertically translatable relative to the workpiece. The first and second fixtures can be horizontally translatable relative to the frame.

[0018] In another aspect, a method for laser scribing a workpiece comprising a substantially flat surface is provided. The method includes supporting the workpiece so that the flat surface is substantially vertically oriented, generating a relative translation between the supported workpiece and a scribing optical assembly, and directing output from a laser with the scribing optical assembly during the relative translation to form a laser-scribed feature on the workpiece. The relative translation comprises a vertical component. In many embodiments, the relative translation further comprises a horizontal component.

[0019] In many embodiments, the workpiece is supported by a frame. For example, the workpiece can be supported with a first fixture engaged with a first portion of the workpiece and a second fixture engaged with a second portion of the workpiece, where the first and second fixtures are coupled with the frame and configured to be horizontally translatable relative to the frame. The scribing optical assembly can be coupled with the frame. In many embodiments, the workpiece is translated horizontally relative to the frame during at least a portion of the formation of the laser-scribed feature. In many embodiments, the method further comprises mounting a second workpiece so that the second workpiece is supported by the frame during at least a portion of the formation of the laser-scribed feature.

[0020] In many embodiments, the workpiece comprises a substrate and at least one layer used for forming a solar cell. In many embodiments, the laser is able to remove material from the at least one layer.

[0021] For a fuller understanding of the nature and advantages of the present invention, reference should be made to the ensuing detailed description and the accompanying drawings. Other aspects, objects and advantages of the invention will be apparent from the drawings and the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is a schematic illustration of a scribed assembly used in a thin-film solar cell.

[0023] FIG. **2**A is a front-view schematic illustration of a laser-scribing apparatus for scribing a vertically-oriented workpiece, in accordance with many embodiments.

[0024] FIG. **2**B is a top-view schematic illustration of a laser-scribing apparatus for scribing a vertically-oriented workpiece, in accordance with many embodiments.

[0025] FIG. **3**A schematically illustrates positions of first and second workpieces in a processing sequence that can be used to laser scribe vertically-oriented workpieces, in accordance with many embodiments.

[0026] FIG. **3**B schematically illustrates positions of first and second workpieces in a processing sequence that can be used to laser scribe vertically-oriented workpieces, in accordance with many embodiments.

[0027] FIG. **3**C schematically illustrates positions of second and third workpieces in a processing sequence that can be used to laser scribe vertically-oriented workpieces, in accordance with many embodiments.

[0028] FIG. **4** schematically illustrates laser-scanning assemblies configured for vertical translation relative to a vertically-oriented workpiece, in accordance with many embodiments.

[0029] FIG. **5**A schematically illustrates components of a laser assembly, in accordance with many embodiments.

[0030] FIGS. **5**B and **5**C schematically illustrate components of a laser-optics module, in accordance with many embodiments.

[0031] FIG. **6** schematically illustrates the use of a beam viewer to measure the position of a laser beam, in accordance with many embodiments.

[0032] FIG. **7** schematically illustrates the integration of an imaging device with a laser-scanning assembly, in accordance with many embodiments.

[0033] FIG. **8** schematically illustrates the integration of a camera with a laser-scanning assembly, showing locations for photodiodes that can be used to measure laser-pulse reflections and illumination source locations, in accordance with many embodiments.

[0034] FIG. **9** diagrammatically illustrates signals between components of a laser-scribing system, in accordance with many embodiments.

[0035] FIG. **10** illustrates a control diagram for a laser-scribing device that can be used in accordance with many embodiments.

[0036] FIG. **11** illustrates a data-flow diagram for a laser-scribing device that can be used in accordance with many embodiments.

[0037] FIG. **12** is a simplified diagram of a system for controlling a scanning device based upon image information of previously formed features, in accordance with many embodiments.

DETAILED DESCRIPTION

[0038] In accordance with various aspects and embodiments of the present disclosure, apparatuses and systems for scribing or otherwise patterning a vertically-oriented workpiece are provided. Laser scribing a vertically-oriented workpiece, for example, may result in improved workpiece stability, improved ablation debris removal, improved throughput, reduced vibration levels, improved accuracy, and other such improvements. For example, laser scribing a vertically-oriented workpiece may reduce the need for air bearings to support the workpiece, which may make it possible to stack two or more workpieces close together, which may enable increased throughput. Such apparatuses and systems may be particularly effective when used to laser-scribe assemblies used to form thin-film solar cells.

[0039] FIG. **2**A schematically illustrates a front view of a laser-scribing tool architecture **30** that can be used in accordance with many embodiments to laser scribe or otherwise pattern a vertically-oriented workpiece, such as the example solar-cell assembly **10** discussed above (shown in FIG. **1**). The tool architecture **30** can include a first fixture **32** and a second fixture **34** for holding a first workpiece **36** in a vertical orientation. The holding fixtures can include any appropriate gripper, clamping device, grasping device, or other such device. The tool architecture **30** can also include additional fixtures, such as a third fixture **38** and a fourth fixture **40** shown, for holding one or more additional workpieces in a vertical orientation (e.g., a second workpiece **42**). Two fixtures can be arranged to engage opposite sides or edges of a rectangular workpiece, for example, by engaging the top and bottom sides or by engaging the left and right sides. Four or more fixtures can be arranged to engage all four sides of a rectangular workpiece. Although as little as one fixture can be used, the use of two or more fixtures may provide increased workpiece stability.

[0040] In many embodiments, the tool architecture **30** includes a first loading/unloading station **44**, a scribing station **46**, a first scribing optical assembly **48**, a second scribing optical assembly **50**, and a second loading/unloading station **52**. These separate stations provide the ability to load and/or unload a workpiece while another workpiece is being scribed. For example, in FIG. **2**A the first workpiece **36** can be scribed while the second workpiece **42** is loaded into the scribing tool via the first loading/unloading station **44**. Although not shown, another workpiece positioned at the second loading/unloading station **52** can be unloaded while the first workpiece **36** is being scribed and the second workpiece **42** is being loaded. It should be understood that the workpieces can travel in either direction. For example, the second loading/unloading station **52** can be used to unload a workpiece that moved left to right in the plane of the figure (e.g., from the scribing station **46** to the second station **52**). The second station **52** can then be used to load another workpiece, which would then move from right to left in the plane of the figure (e.g., from the second station **52** to the scribing station **46**). In many embodiments, the fixtures move back to a designated loading station after a workpiece is unloaded at a designated unloading station such that workpieces are always loaded at the designated loading station and unloaded at the designated unloading station. In many embodiments where a single rail is used, each loading/unloading station can serve as a loading and unloading station for a workpiece. For example, a workpiece loaded via the first loading/unloading station **44** can move to the right to the scribing station **46** and then move back to the left to be unloaded at the first loading/unloading station **44**, thereby never reaching the second loading/unloading station **52**. In such an approach, the second loading/unloading station **52** can be occupied by the fixtures **32**, **34** for use in supporting a workpiece loaded and unloaded via the second loading/unloading station **52**. In many embodiments where a single rail is used, the fixtures cannot pass each other on the same rail, so fixture **38** is necessarily always to the left of fixture **32** in the figure. In many embodiments, separate rails are used as discussed below.

[0041] In many embodiments, a first scribing optical assembly **48** and a second scribing optical assembly **50** are configured to translate vertically relative to the workpiece so as to provide a desired area of coverage on the workpiece. Each scribing optical assembly can be coupled with one or more lasers (see FIG. **4**) via an optical path, for example, via an optical path comprising an optical fiber or other optical element. Each optical assembly also can include one or more laser scanning heads (e.g.; a one, two, or three-dimensional scanner able to direct each beam in one, two, or three dimensions, respectively) that provide the ability to control the position of the output of a laser beam relative to each scanning head. In many embodiments, there is one laser for each scanner, while in many other embodiments a laser beam is split into multiple beams, such as by using an appropriate beam-splitting element, which can be directed to different scanners. In many embodiments, only a single laser is used. In many embodiments that use optical fibers, the optical fibers can be selected to such that the optical path length is the substantially equivalent for each scanner.

[0042] FIG.**2**B schematically illustrates a top-view of a laser-scribing tool architecture **60** in accordance with many embodiments, that utilizes a frame with separate, substantially parallel rails or tracks **72**, **74**. In many embodiments, the tool architecture **60** is a variation of the tool architecture **30** shown in FIG. **2**A, and thus can contain many of the same or similar components. The tool architecture **60** includes a first loading/unloading station **62**, a scribing station **64**, a first scribing optical assembly **66**, a second scribing optical assembly **68**, a second loading/unloading station **70**, and what will be referred to herein as a “front” workpiece track **72** and a “back” workpiece track **74**, although these designations should not infer any particular or preferred orientation. The separate workpiece tracks may allow a workpiece to be loaded or unloaded on one track while another workpiece is being processed (e.g., scribed or patterned) on the other track. The use of separate workpiece tracks may reduce the transmission of vibrations to a workpiece that is being scribed on one track by providing for the ability to load and/or unload workpieces on the other track. For example, a first workpiece **76** can be scribed while secured to the back workpiece track **74** while a second workpiece **78** can be loaded via the front workpiece track **72**. The first scribing optical assembly **66** and the second scribing optical assembly **68** can be configured to move horizontally (in a direction transverse to the direction of motion of the workpieces) so as to be positioned at the same distance from a workpiece regardless of what track the workpiece is on. For example, in the plane of the figure the optics move "up" toward the back track **74** to process the first workpiece **76** on the back track, but would move back "down" away from the back track to process the second workpiece **78** on the front track **72**.

[0043] FIGS. **3**A, **3**B, and **3**C schematically illustrate a processing sequence, in accordance with many embodiments, for laser-scribing vertically-oriented workpieces. In FIG. **3**A, a first workpiece **80** can be loaded via a first loading/unloading station **86** onto a first track (e.g., a front track) and then moved continually to the right in the figure to be scribed in the scribing station **82**. During scribing of the first workpiece **80**, a second workpiece **84** can be loaded via station **86** onto a second track (e.g., a back track). Each workpiece can be aligned in station **86** using one or more previously formed features. Optionally, a workpiece can be marked with bar coding and/or other designating marks for use in alignment. In FIG. **3**B, the first workpiece **80** can be unloaded at a second loading/unloading station **88** after being processed, while the second workpiece **84** can be scribed in the scribing station **82**. In many embodiments, a workpiece can be held stationary or translated during any particular portion of the scribing process. As discussed, the optics or scan heads can be adjusted horizontally (toward or away from the workpiece) to maintain a substantially constant distance from each workpiece being processed. As illustrated in FIG. **3**C, the fixtures on the first track can move back to the station **86** such that a third workpiece **90** can be loaded (and optionally aligned and/or marked) in the station **86** while the second workpiece **84** is being scribed in the scribing station **82**.

[0044] FIG. **4** schematically illustrates example laser-scanning assemblies, in accordance with many embodiments, configured for vertical translation relative to a vertically-oriented workpiece **92**. Such laser-scanning assemblies can be used with a system such as those described above. A first laser-scanning assembly **94** can be coupled with a first laser source **96** by way of a first optical path **98** (e.g., an optical fiber, an optical path). A second laser-scanning assembly **100** can be coupled with a second laser source **102** by way of a second optical path **104**. The laser-scanning assemblies can be configured to move in opposite directions so as to minimize any unbalanced forces that may arise due to the movement of the scanning assemblies. For example, by having the first laser-scanning assembly **94** move in the opposite direction of the second laser-scanning assembly **100** the resulting forces generated by the acceleration of the assemblies cancel out so that there is no resulting force on a frame holding these assemblies. The scanning assemblies can be configured to translate using known approaches, for example, by using a robotic arm, a rail, a gantry, or any other known mechanism. Each optical assembly can include one or more separate laser-scanning heads **106**, which can be used to control the position on the workpiece of output from the laser source in one or more dimensions relative to the scanning head. A combination of the local control provided by a scanning head, the number and placement of scanning heads, the vertical and optionally horizontal movement of a scanning assembly, and the horizontal movement of the workpiece can be used to scribe desired areas of the workpiece. Fiber-optic cables can be used to couple a scanning assembly with a laser source. The use of fiber-optic cables may reduce the weight of moving parts, thereby helping to reduce movement induced forces and/or vibrations. In many embodiments, the use of fiber-optic cables would also eliminate the need for complex optical alignment.

[0045] A variety of potential variations can be employed. For example, although the workpiece **92** is shown as being clamped at the top and bottom, optionally the workpiece can be clamped on the sides, or on any combination of the top, bottom and sides. In many embodiments, the workpiece is translated at low speeds (e.g., 5 to 10 mm/sec) during the scribing process, for example, via a ball screw over a range of travel (e.g., 275 mm). In many embodiments, the laser-scanning assemblies **94**, **100** produce eight beams and are spaced apart at 275 mm spacing in the horizontal direction. In many embodiments, the laser-scanning assemblies **94**, **100** are equipped with two-dimensional laser-scanning heads **106** with a field-of-view (FOV) of approximately 60 mm. In many embodiments, the laser-scanning assemblies **94**, **100** are translatable in the vertical direction at a relatively high speed (e.g., 0.5 to 2 or more meters/sec). In many embodiments, the laser-scanning assemblies **94**, **100** are supported via air bearings. In many embodiments, the laser-scanning assemblies **94**, **100** have a total travel of approximately 3 meters. In many embodiments, the laser-scanning heads **106** compensate for movement of the workpiece during the scribing process (e.g., via bowtie scanning). In many embodiments, the laser-scanning assemblies **94**, **100** move in opposite directions to minimize motion induced forces. In many embodiments, the laser-scanning assemblies **94**, **100** are translatable in the z direction (i.e., in and out of the plane of the figure) to compensate for the location of each workpiece. In many embodiments, lateral trim lines can be produced using scanner stitching during vertical motion of the laser-scanning assemblies.

[0046] In many embodiments, each workpiece is moved continually in a first direction, wherein the scan field for each beam portion forms a scribe line moving "up" or "down" the workpiece. The laser repetition rate can be matched to the stage translation speed, with a necessary region of overlap between scribe positions for edge isolation. At the end of a scribing pass up or down the workpiece, each scanning assembly can decelerate, stop, shift as necessary, and re-accelerate in the opposite direction. In this case, the laser optics are stepped according to the required pitch so that the series of ablation spots used to form the scribe lines are laid down at the required positions on the glass substrate. If the scan fields overlap, or at least substantially meet within a pitch between successive scribe lines, then the substrate does not need to be moved relative to the laser-scanning assemblies, but the beam position can be adjusted between "up" and "down" movements of the laser-scanning assemblies in the laser-scribe device. In many embodiments, the laser can scan across the workpiece making a scribe mark at each position of a scribe line within the scan field, such that multiple scribe longitudinal scribe lines can be formed at the same time with only one complete pass of the laser-scanning assemblies being necessary. Many other scribe strategies can be supported as would be apparent to one of ordinary skill in the art in light of the teachings and suggestions contained herein.

[0047] Laser Assemblies

[0048] Further, while four lasers are shown for each of two scanning assemblies for a total of eight active beams, it should be understood that any appropriate number of lasers and/or beam portions can be used as appropriate, and that a beam from a given laser can be separated into as many beam portions as is practical and effective for the given application.

Further, even in a system where two lasers produce eight beam portions, fewer than eight beam portions can be activated based on the size of the workpiece or other such factors. Optical elements in the scan heads also can be adjusted to control an effective area or spot size of the laser pulses on the workpiece, which in many embodiments vary from about 25 microns to about 100 microns in diameter.

[0049] Each laser-scanning assembly can including appropriate elements, such as lenses and other optical elements, needed to focus or otherwise adjust aspects of the laser beam. The laser device generating the beam can be any appropriate laser device operable to ablate or otherwise scribe at least one layer of the workpiece, such as a pulsed solid-state laser. In order to provide the pair of beams, each laser assembly can include at least one beam-splitting device. FIG. **5**A illustrates basic elements of an example laser assembly **200** that can be used in accordance with many embodiments, although it should be understood that additional or other elements can be used as appropriate. In this assembly **200**, a single laser device **202** generates a beam that is expanded using a beam collimator **204** then passed to a beam splitter **206**, such as a partially transmissive mirror, half-silvered mirror, prism assembly, etc., to form first and second beam portions. In this assembly, each beam portion passes through an attenuating element **208** to attenuate the beam portion, adjusting an intensity or strength of the pulses in that portion, and a shutter **210** to control the shape of each pulse of the beam portion. Each beam portion then also passes through an auto-focusing element **212** to focus the beam portion onto a scan head **214**. Each scan head **214** includes at least one element capable of adjusting a position of the beam, such as a galvanometer scanner useful as a directional deflection mechanism. In many embodiments, this is a rotatable mirror able to adjust the position of the beam along a lateral direction, orthogonal to the movement vector of the workpiece, which can allow for adjustment in the position of the beam relative to the intended scribe position. The scan heads then direct each beam concurrently to a respective location on the workpiece. A scan head also can provide for a short distance between the apparatus controlling the position for the laser and the workpiece. Therefore, accuracy and precision is improved. Accordingly, the scribe lines can be formed more precisely (i.e., a scribe 1 line can be closer to a scribe 2 line) such that the efficiency of a completed solar module is improved over that of existing techniques.

[0050] In many embodiments, each scan head **214** includes a pair of rotatable mirrors **216**, or at least one element capable of adjusting a position of the laser beam in two dimensions (2D). Each scan head includes at least one drive element **218** operable to receive a control signal to adjust a position of the "spot" of the beam within the scan field and relative to the workpiece. In some embodiments, a spot size on the workpiece is on the order of tens of microns within a scan field of approximately 60 mm×60 mm, although various other dimensions are possible. While such an approach allows for improved correction of beam position on the workpiece, it can also allow for the creation of patterns or other non-linear scribe features on the workpiece. The ability to laterally scan the beam (e.g., in one or more dimensions) means that any pattern can be formed on the workpiece via scribing without having to rotate the workpiece. Additionally, the ability to laterally scan the beam allows for vertical lines to be scribed on the glass by combining the motion of the glass in the horizontal direction, the motion of the optics assembly in the vertical direction, and positional scanning by the scanner so that the resulting scribe on the glass is parallel to the vertical edge of the glass, an approach that is sometimes referred to as bow-tie scanning.

[0051] FIGS. **5**B and **5**C show a side-view illustration and a top-view illustration, respectively, of a compact laser-optics module **220** that can be used in accordance with various embodiments. The compact module **220** includes a laser **222**, a beam collimator **224**, a beam splitter **226**, a mirror **228**, one or more scanning mirrors **230**, **232**, and one or more focusing optical assemblies **234**. The laser **222** can comprise a range of existing lasers. For example, the laser **222** can comprise a lightweight, small footprint laser. Existing second harmonic solid state lasers of sufficient power for scribing thin-film solar panel scribe lines can be made as light as 1 kg with a size of approximately 150 mm by 100 mm by 50 mm. A laser power supply and/or chiller can be located exterior to the compact module **220**. The laser **222** generates a beam that is collimated using the beam collimator **224**. The beam collimator **224** can be used to change the size of the laser beam and can be coupled with the laser **222**, for example, attached to the laser adjacent to the output of the laser **222**. The beam splitter **226** receives the collimated beam from the collimator **224** and splits the collimated beam into two nominally equal beam portions. In many embodiments, a power-attenuation aperture (not shown) can be placed along each beam path to finely adjust laser power and beam size. In many embodiments, an attenuating element (see attenuating element **208** in FIG. **5**A) can be placed along each beam path to attenuate the beam portion, adjusting an intensity or strength of the pulses in that portion. In many embodiments, a shutter (see shutter **210** in FIG. **5**A) can be placed along each beam path to control the shape of each pulse of the beam portion. In many embodiments, an auto-focusing element (see auto-focusing element **212** in FIG. **5**A) can be placed along each beam path to focus the beam portion onto the one or more scanning mirrors. The one or more scanning mirrors **230**, **232** can be actuated about one or more axes, for example, one or more galvanic scanning mirrors can be actuated about an x-axis and a y-axis to provide for two-dimensional scanning of the laser output. In many embodiments, the one or more scanning mirrors **230**, **232** comprise individual galvanic scanning mirrors as opposed to a scan head (e.g., scan head **214** in FIG. **5**A). Each of the scanned beam portions can then be passed through a focus optical assembly **234**, which in many embodiments comprises a telecentric lens.

[0052] In many embodiments, the compact module **220** provides the functionality of the laser assembly **200** (shown in FIG. **5**A) and various advantages. For example, the layout, rigidity, footprint, and/or weight of the compact module **220** may have a positive direct impact on the reliability and serviceability of the compact module **220** and the whole laser-scribing system. In many embodiments, the use of a single beam collimator before the beam is split may provide a simplified optical beam path and enhanced reliability. In many embodiments, the use of two individual scanning mirrors in place of an enclosed commercial scan head may help to reduce the weight and footprint of the compact module **220**, which may serve to improve reliability and serviceability. In many embodiments, the use of a light weight all-in-one box laser module may be easier to install/uninstall and may serve to isolate the optical components from dust, which may reduce the chance for contamination of the optical components.

[0053] Sensors

[0054] A laser-scribing system can include a number of sensors useful for controlling the scribing of laser lines on a workpiece. For example, as illustrated in FIG. **6**, a beam viewer **302** can be used to measure the position of the output from the laser. Data from the beam viewer **302** can be used for rapid recalibration of the beam position. As illustrated, the beam viewer **302** can be positioned relative to a workpiece **304** so as to capture the position of a beam **306** as it passes through the workpiece **304**. The expected and the actual position of the beam **306** can be compared to calculate a correction, which can provide a highly accurate adjustment for the correction of any drifts that occur. The beam measured can be projected by a laser assembly **310** that includes a laser **312**, beam split optics **314**, and scanners **316**. As discussed above, the laser assembly **310** can be located on an optics gantry (not shown). A power meter (not shown) can also be positioned on the optics gantry for monitoring the laser power incident on the glass. A microscope (not shown) can also be used. A primary function of the microscope is calibration and alignment of the glass. The microscope can also be used to observe the scribe quality and measure the size of ablation spots. A line sensor **318** can also be used to generate location data for previously formed features. The line sensor **318** can be located in a number of locations from which it can view the previously formed features, for example, relative to the workpiece **304** as illustrated.

[0055] Imaging Devices

[0056] In many embodiments, one or more cameras is used to optically observe a previously laser-scribed line and align the position of the output from the scribing laser relative to the previously laser-scribed line on the workpiece. In many embodiments, one or more cameras are mounted so that the center of the camera view and the output of a scanning assembly point at the same position on a workpiece. In many embodiments, one or more cameras are mounted to view the workpiece independent of the scanning assemblies.

[0057] FIG. **7** schematically illustrates a laser-scanning assembly **400** in accordance with many embodiments. The laser assembly **400** is similar to the previously discussed laser assembly **200** of FIG. **5**A, but further includes two imaging devices **420** (e.g., CCD cameras shown) integrated with the laser assembly **400** so that each of the imaging devices **420** can view the workpiece through an associated scanner **414**. As shown, each of the imaging devices **420** can be integrated using a dichromatic beam splitter **406** so as provide the imaging device with a view direction that substantially corresponds with the direction along which a separate laser beam portion is provided to each of the scanners **414**. As discussed above, although a range of relative positions can be practiced, an imaging device **420** can be integrated with the laser assembly **400** so that the center of its view and the output of the scribing laser **402** point at the same position on a workpiece being targeted by the scanner **414**.

[0058] FIG. **8** schematically illustrates a laser-scanning assembly **500** with an integrated camera **502**, in accordance with many embodiments. The laser-scanning assembly **500** includes a laser **504** that supplies a laser beam to a scan head **506**. The laser beam passes through a dichroic beam splitter **508** on its way to the scan head **506**. As described above, the scan head **506** can include at least one element capable of adjusting a position of the laser beam, such as a galvanometer scanner useful as a directional deflection mechanism. The scan head **506** includes a telecentric scan lens **510** that can provide for redirection of a scanned laser beam so as to impinge upon a workpiece **512** in a direction that is substantially normal to the workpiece **512**. The laser-scanning assembly **500** includes a camera **502** that is integrated so as to view the workpiece through the scan head. The camera **502** can be used to capture light that is reflected from the workpiece. The reflected light from the workpiece travels through the telecentric lens **510**, is redirected by the scan head toward the laser **504**, is reflected by the dichroic beam splitter **508**, and travels through the imaging lens **514** where the reflected light is received by the camera **502**. A photo diode **516**, which can be used to measure laser-pulse reflections from the scan lens **510** or from the workpiece **512**, can be located in a variety of locations, such as those shown. Where a photodiode **516** is located adjacent to the camera **502**, the laser-scanning assembly **500** can include a beam splitter **518** so as to redirect reflected light toward the photodiode. An illumination sources **520** can also be used to supply illumination used for image capture. The illumination sources **520** can be located in various locations, for example, in the locations shown.

[0059] Control Systems

[0060] A Vertically-oriented workpiece scribing system can include a control system operable to control the movement of the fixtures, the movement of the scanning assemblies, the operation of the lasers and scanning devices, etc. The control system can include any appropriate combination of hardware and software, and can include any appropriate motor or drive mechanisms necessary for operation. The system can include any number of sensors or monitors, and can include one or more feedback systems to monitor and adjust operation.

[0061] FIG. **9** diagrammatically illustrates signals between components of a scribing system **600**, in accordance with many embodiments. A stage motion controller **602** can be used to move a workpiece relative to a scan head. Alternatively, the scan head can be moved relative to the workpiece or a combination of movement of the workpiece and the scan head can be used. The stage motion controller **602** can transfer its positional information to a scan controller **604**, including start and stop signals. The scan controller **604** can send fire control signals to a laser **606**, including first pulse suppression and off signals. As describe above, an imaging device **608** can supply image-derived data regarding the positions of features on the workpiece to a processor **610**. The processor **610** can generate a correction signal that can be supplied to the scan controller **604** for the correction of subsequently commanded scan locations of a scan head used to target output from the laser **606** on the workpiece. At the beginning of the formation of a scribe line relative to a previously-formed scribed line, excess space can be allowed. As the formation of the scribe line progresses, the control system can rapidly close in on a desired line spacing. The system can operate to track lines and maximize active area by keeping P1 close to P2 and P3 close to P2.

[0062] FIG. **10** illustrates a control system **700** that can be used for a laser-scribe device in accordance with many embodiments, although many variations and different elements can be used as would be apparent to one of ordinary skill in the art in light of the teachings and suggestions contained herein. In this system, a workstation **702** works through a Virtual Machine Environment (VME) controller **704**, such as by using an Ethernet connection, to work with a pulse generator **706** (or other such device) for driving the workpiece translation stage **708** and controlling a strobe lamp

710 and an imaging device **712** for generating images of the scribe position(s). The workstation also works through the VME controller **704** to drive the position of each scanner **714**, or scan head, to control the spot position of each beam portion on the workpiece, and to control the firing of the laser **716** via a laser controller **718**. FIG. **11** illustrates a flow of data **800** through these various components.

[0063] In many embodiments, scribe placement accuracy is guaranteed by synchronizing the workpiece translation stage encoder pulses to the laser and spot placement triggers. The system can ensure that the workpiece is in the proper position, and the scanners directing the beam portions accordingly, before the appropriate laser pulses are generated. Synchronization of all these triggers is simplified by using the single VME controller to drive all these triggers from a common source. Various alignment procedures can be followed for ensuring alignment of the scribes in the resultant workpiece after scribing. Once aligned, the system can scribe any appropriate patterns on a workpiece, including fiducial marks and bar codes in addition to cell delineation lines and trim lines.

[0064] FIG. **12** is a simplified block diagram of a control system **900** that can be used, in accordance with embodiments. The control system **900** can include at least one processor **902**, which can communicate with a number of peripheral devices via bus subsystem **904**. The peripheral devices can include a storage subsystem **906**, which includes, for example, a memory subsystem **908** and a file storage subsystem **910**. The storage subsystem **906** can maintain basic programming and data constructs that can be used to control a patterning device. The peripheral devices can also include a set of user interface input and output devices **912**.

[0065] The user interface input devices can include a keyboard and may further include a pointing device and a scanner. The pointing device can be an indirect pointing device such as a mouse, trackball, touchpad, or graphics tablet, or a direct pointing device such as a touch screen incorporated into the display. Other types of user interface input devices, such as voice recognition systems, are also possible.

[0066] User interface output devices can include a printer and a display subsystem, which can include a display controller and a display device coupled to the controller. The display device can be a cathode ray tube (CRT), a flat-panel device such as a liquid crystal display (LCD), or a projection device. The display subsystem can also provide non-visual display such as audio output.

[0067] The memory subsystem **908** typically includes a number of memories including a main random access memory (RAM) **914** for storage of instructions and data during program execution and a read only memory (ROM) **916** in which fixed instructions are stored.

[0068] The file storage subsystem **910** provides persistent (non-volatile) storage for program and data files, and typically includes at least one hard disk drive and at least one disk drive (with associated removable media). There may also be other devices such as a CD-ROM drive and optical drives (all with their associated removable media). Additionally, the system may include drives of the type with removable media cartridges. One or more of the drives may be located at a remote location, such as in a server on a local area network or at a site on the Internet's World Wide Web.

[0069] In this context, the term "bus subsystem" is used generically so as to include any mechanism for letting the various components and subsystems communicate with each other as intended. With the exception of the input devices and the display, the other components need not be at the same physical location. Thus, for example, portions of the file storage system could be connected via various local-area or wide-area network media, including telephone lines. The bus subsystem **904** is shown schematically as a single bus, but a typical system has a number of buses such as a local bus and one or more expansion buses (e.g., ADB, SCSI, ISA, EISA, MCA, NuBus, or PCI), as well as serial and parallel ports.

[0070] Discussion of the remaining items of FIG. **12** will be omitted here due to being discussed above, such as a workpiece stage **918**, a scanner **920**, an imaging device **922**, and other miscellaneous laser-scribing device **924** components.

[0071] Additional Features

[0072] In many embodiments, a laser-scribing system includes one or more additional features. For example, an exhaust hood or other exhausting means can be positioned to extract material ablated from a workpiece. In many embodiments, there is at least one exhaust for each workpiece. In many embodiments, the layers to be scribed are on the opposite side of the workpiece from the scanning assemblies, such that the laser beams pass through the substrate to scribe the layers, thus causing the material to ablate off the surface where it can be extracted by an exhaust system.

[0073] Additional devices, apparatus, systems, and methods that can be used with the presently disclosed laser-scribing tool architecture and methods are described in numerous patent applications assigned to Applied Materials, Inc. including, for example, in U.S. patent application Ser. No. 12/422,189 entitled "LASER SCRIBING PLATFORM AND HYBRID WRITING STRATEGY," filed Apr. 10, 2009; U.S. patent application Ser. No. 12/422,200 entitled "LASER-SCRIBING PLATFORM," filed Apr. 10, 2009; U.S. patent application Ser. No. 12/422,224 entitled "LASER SCRIBE INSPECTION METHODS AND SYSTEMS," filed Apr. 10, 2009; U.S. patent application Ser. No. 12/422,208 entitled "DYNAMIC SCRIBE ALIGNMENT FOR LASER SCRIBING, WELDING OR ANY PATTERNING SYSTEM," filed Apr. 10, 2009; U.S. patent application Ser. No. 12/430,249 entitled "DEBRIS-EXTRACTION EXHAUST SYSTEM," filed Apr. 27, 2009; and U.S. patent application Ser. No. 12/430,345 entitled "IN-SITU MONITORING FOR LASER ABLATION," filed Apr. 27, 2009, the entire disclosures of which are hereby incorporated herein by reference.

[0074] It is understood that the examples and embodiments described herein are for illustrative purposes and that various modifications or changes in light thereof will be suggested to a person skilled in the art and are to be included within the spirit and purview of this application and the scope of the appended claims. Numerous different combinations are possible, and such combinations are considered to be part of the present invention.

What is claimed is:

1. An apparatus for laser scribing a workpiece comprising a substantially flat surface, the apparatus comprising:

a frame;

a first fixture coupled with the frame, the first fixture being configured for engagement with a first portion of the workpiece;

a second fixture coupled with the frame, the second fixture being configured for engagement with a second portion of the workpiece, wherein when the workpiece is engaged by the first and second fixtures the flat surface is substantially vertically oriented;

a laser operable to generate output able to remove material from at least a portion of the workpiece; and

a scanning device coupled with the laser and the frame, the scanning device operable to control a position of the output from the laser relative to the workpiece.

2. The apparatus of claim **1**, wherein:

the workpiece is substantially rectangular and comprises a first side and a second side opposite the first side;

the first fixture is configured to engage the workpiece along the first side; and

the second fixture is configured to engage the workpiece along the second side.

3. The apparatus of claim **2**, wherein when the workpiece is engaged by the first and second fixtures:

the first side is disposed at the top of the workpiece; and

the second side is disposed at the bottom of the workpiece.

4. The apparatus of claim **2**, wherein when the workpiece is engaged by the first and second fixtures, the first and second sides are substantially vertically oriented.

5. The apparatus of claim **1**, wherein the first and second fixtures are horizontally translatable relative to the frame.

6. The apparatus of claim **5**, comprising:

a third fixture coupled with the frame, the third fixture configured to engage a second workpiece along a first side of the second workpiece; and

a fourth fixture coupled with the frame, the fourth fixture configured to engage the second workpiece along a second side of the second workpiece, wherein

when the second workpiece is engaged by the third and fourth fixtures a flat surface of the second workpiece is substantially vertically oriented, and

the third and fourth fixtures are horizontally translatable relative to the frame.

7. The apparatus of claim **6**, wherein the second workpiece can be loaded while the workpiece is being scribed.

8. The apparatus of claim **7**, wherein the workpiece can be unloaded while the second workpiece is being scribed.

9. The apparatus of claim **8**, wherein a path of travel for the workpiece is offset from a path of travel for the second workpiece.

10. The apparatus of claim **9**, wherein the scanning device is horizontally translatable so as to adjust for the offset between the paths of travel for the workpiece and the second workpiece.

11. The apparatus of claim **1**, wherein the scanning device is vertically translatable relative to the workpiece.

12. The apparatus of claim **11**, wherein the scanning device is vertically translatable relative to the frame.

13. The apparatus of claim **1**, comprising a second scanning device coupled with the laser and the frame, the second scanning device operable to control a position of the output from the laser relative to the workpiece.

14. The apparatus of claim **13**, wherein the scanning device and the second scanning devices are vertically translatable relative to the workpiece.

15. The apparatus of claim **14**, comprising:

an optical cable for coupling the laser with the scanning device; and

a second optical cable for coupling the laser with the second scanning device.

16. The apparatus of claim **1**, comprising an optical cable for coupling the laser with the scanning device.

17. The apparatus of claim **1**, wherein the workpiece comprises a substrate and at least one layer used for forming a solar cell, and the laser is able to remove material from the at least one layer.

18. A system for laser scribing a workpiece comprising a substantially flat surface, the system comprising:

a frame;

a first fixture coupled with the frame, the first fixture being configured for engagement with a first portion of the workpiece;

a second fixture coupled with the frame, the second fixture being configured for engagement with a second portion of the workpiece, wherein when the workpiece is engaged by the first and second fixtures the flat surface is substantially vertically oriented;

a laser operable to generate output able to remove material from at least a portion of the workpiece;

a scanning device coupled with the laser and the frame, the scanning device operable to control a position of the output from the laser relative to the workpiece; and

a control device coupled with the laser and the scanning device, the control device comprising a processor and a machine-readable medium comprising instructions that when executed by the processor cause the system to align the laser output in order to form a predetermined feature pattern on the workpiece.

19. The system of claim **18**, wherein the scanning device is vertically translatable relative to the workpiece.

20. The system of claim **19**, wherein the first and second fixtures are horizontally translatable relative to the frame.

21. A method for laser scribing a workpiece comprising a substantially flat surface, the method comprising:

supporting the workpiece so that the flat surface is substantially vertically oriented;

generating a relative translation between the supported workpiece and a scribing optical assembly, the relative translation comprising a vertical component; and

directing output from a laser with the scribing optical assembly during the relative translation to form a laser-scribed feature on the workpiece.

22. The method of claim **21**, wherein the relative translation further comprises a horizontal component.

23. The method of claim **22**, wherein:

the workpiece is supported with a first fixture engaged with a first portion of the workpiece and a second fixture engaged with a second portion of the workpiece, the first and second fixtures being coupled with a frame and configured to be horizontally translatable relative to the frame;

the scribing optical assembly is coupled with the frame; and

the workpiece is translated horizontally relative to the frame during at least a portion of the formation of the laser-scribed feature.

24. The method of claim **23**, further comprising mounting a second workpiece so that the second workpiece is supported by the frame during at least a portion of the formation of the laser-scribed feature.

25. The method of claim **24**, wherein the workpiece comprises a substrate and at least one layer used for forming a solar cell, and the laser is able to remove material from the at least one layer.

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